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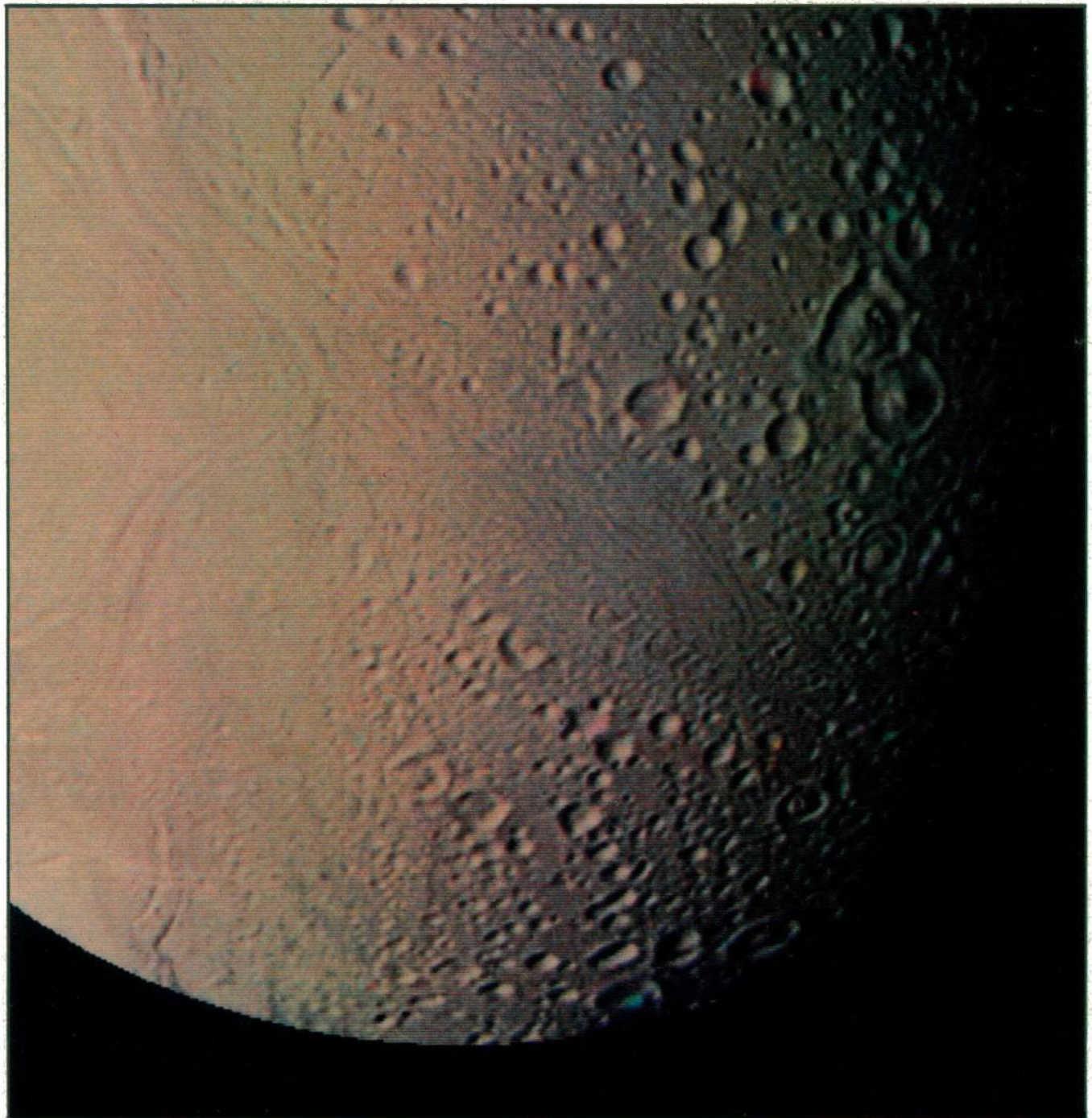
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A Closer Look at Saturn's Moons

The Search for Extrasolar Planets
Paint the Night Sky on Your Ceiling

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Craters and Cracks on Enceladus



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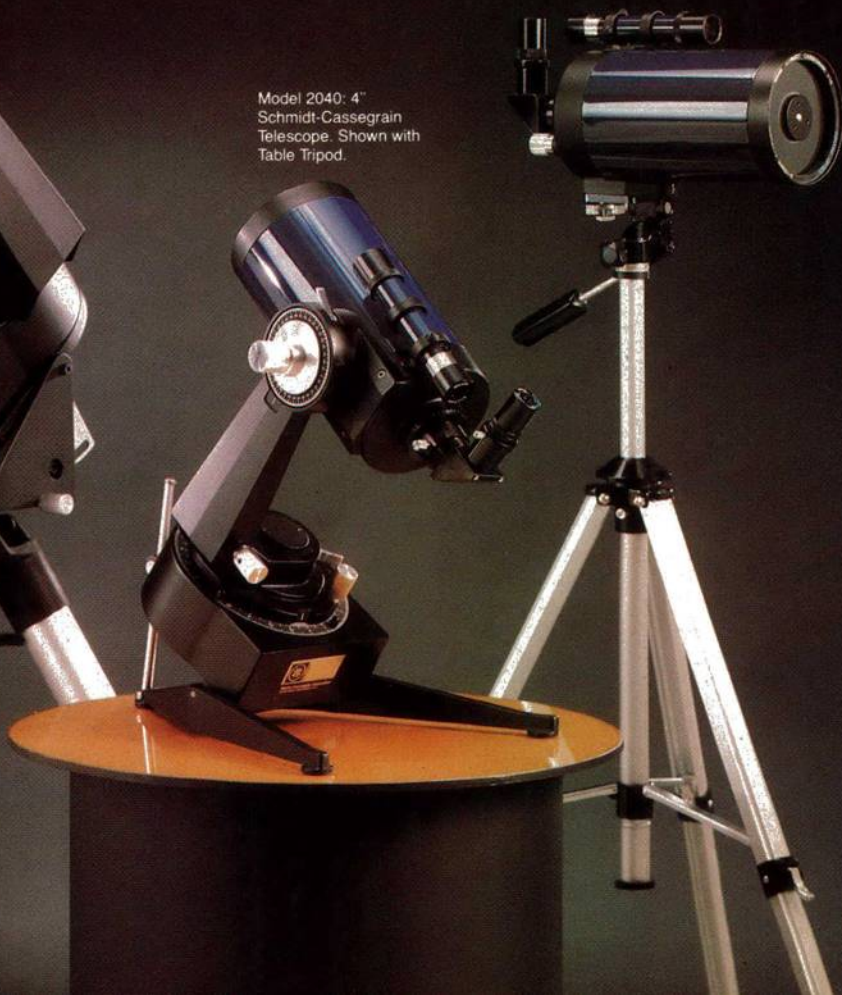
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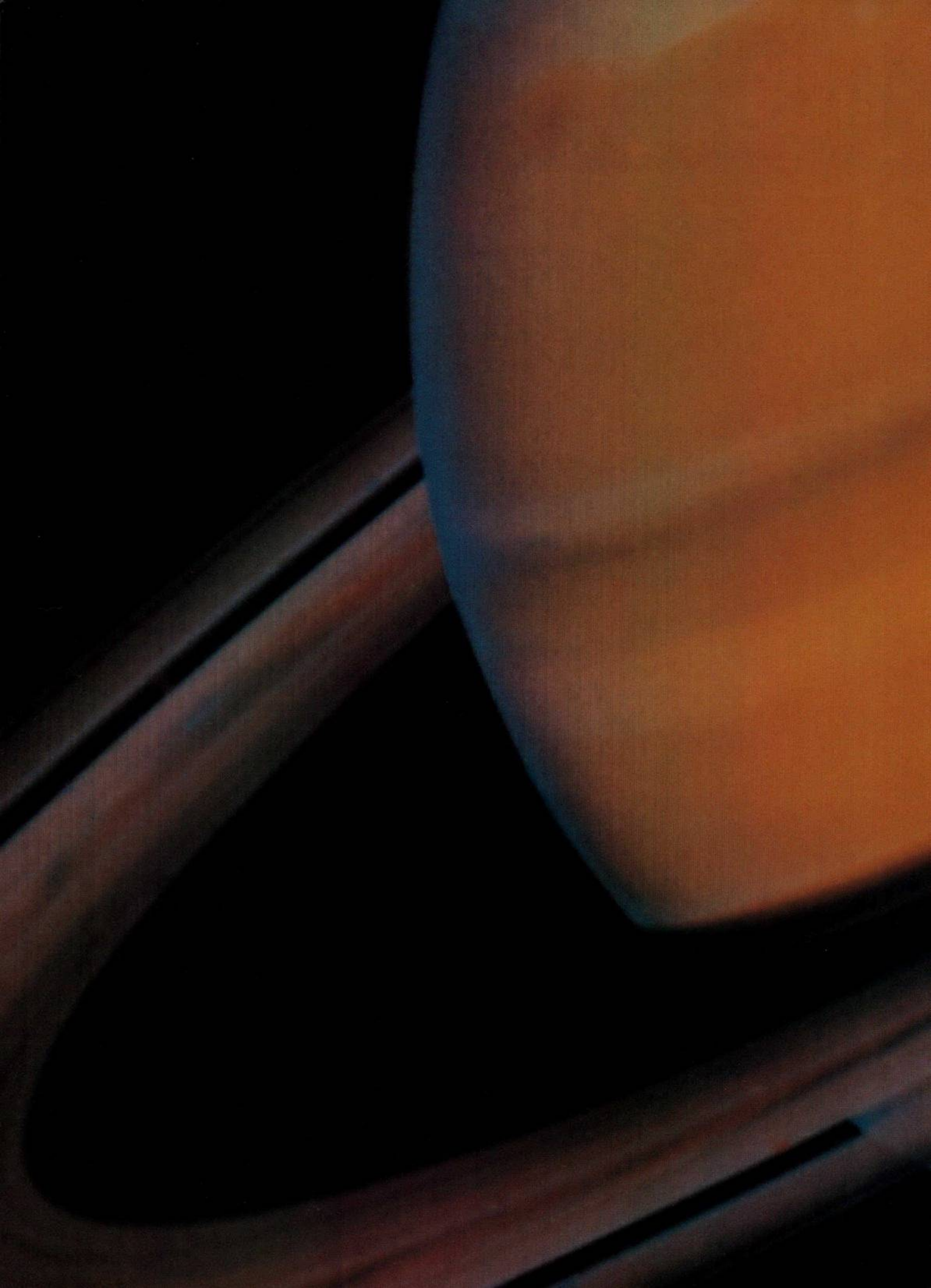
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Note: See Meade Catalog for detailed specifications and standard-accessories listings of telescope models shown.

Model 1020: 1000mm f/10 Telephoto Lens. Attaches to any standard camera tripod. Shown with optional Meade Photo Tripod.





ASTRONOMY

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Cover: The icy saturnian moon Enceladus has a young surface replete with craters, grooves, plains, and strange features unseen elsewhere in the solar system. This month's lead article brings you the complete story on the Saturn moons. These pages: Saturn imaged by Voyager's telephoto lens from 14 million kilometers. Note the storm in the middle latitudes, just below the light orange jet stream. JPL/NASA photographs.

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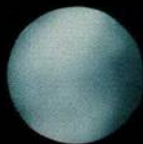
the Saturnian Satellites

by Robert Burnham

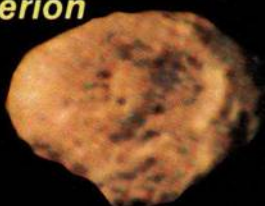
Enceladus



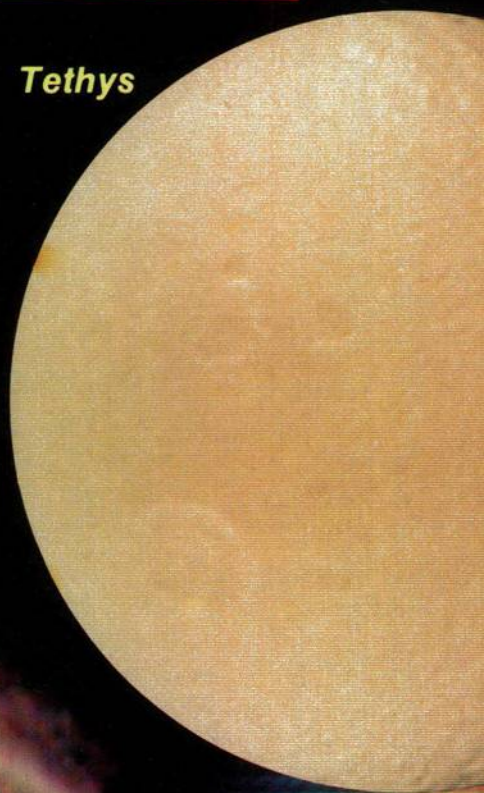
Phoebe



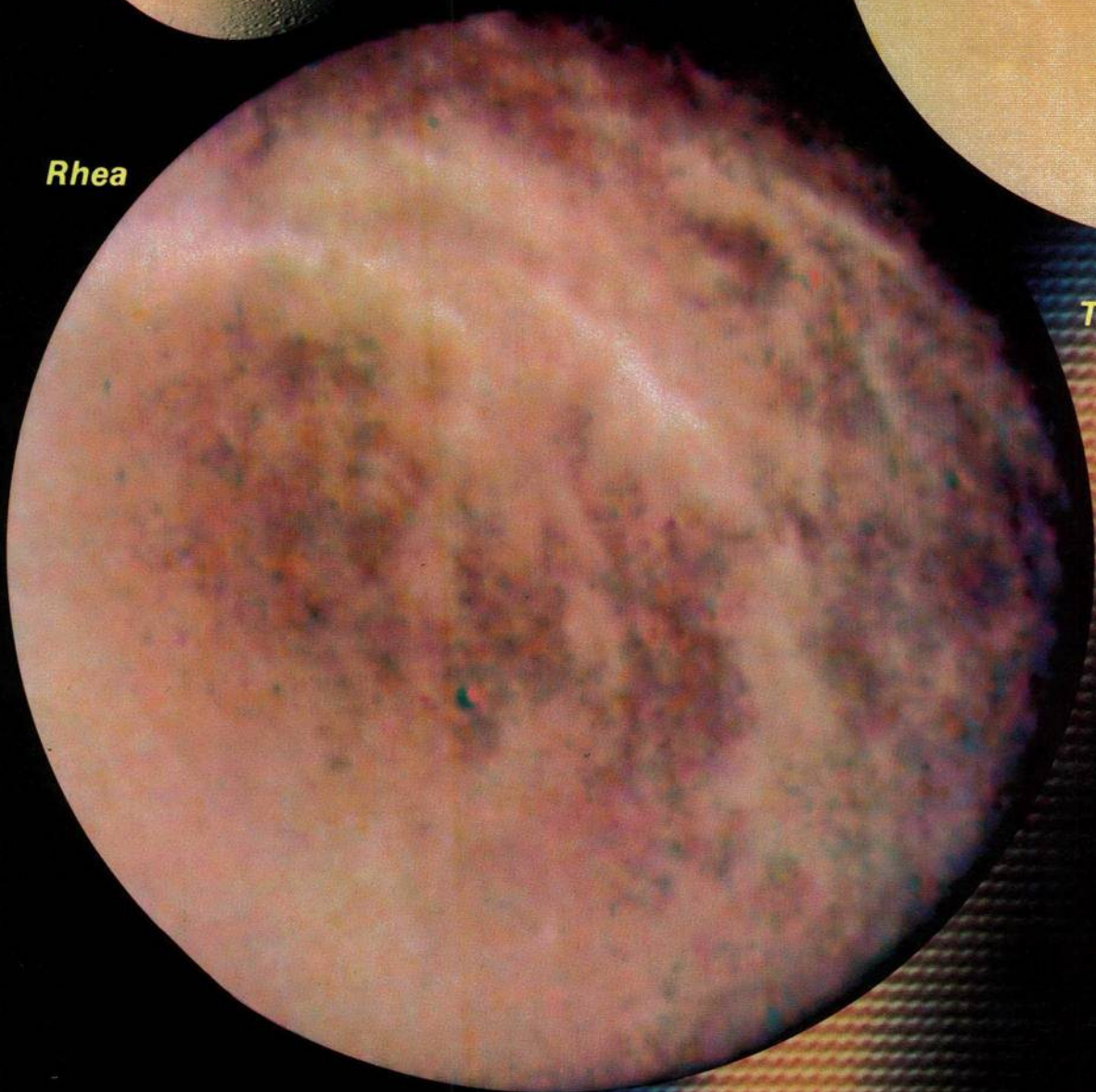
Hyperion



Tethys



Rhea

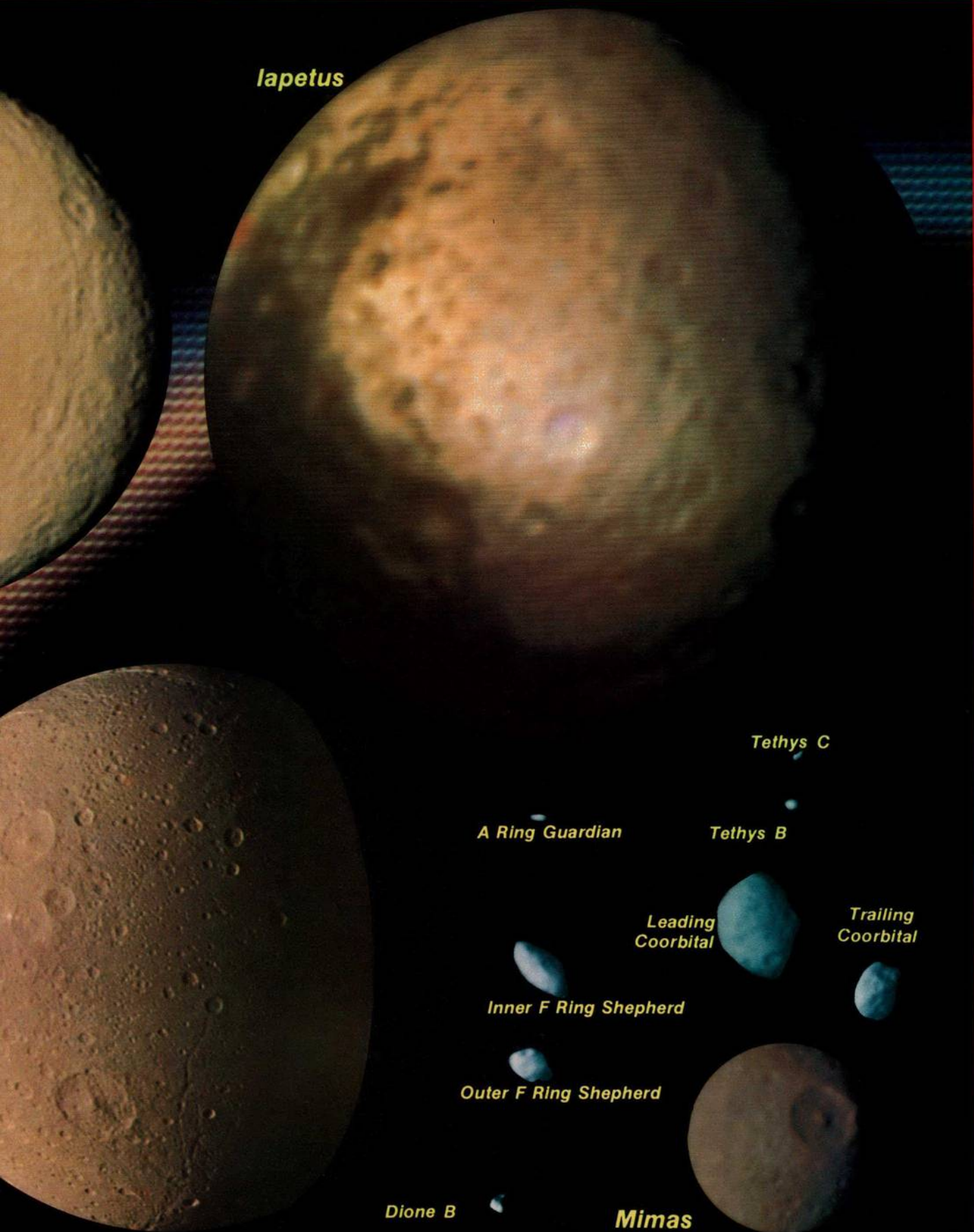


Titan

Dione

Scale: 1:10,000,000

Iapetus



Tethys C

A Ring Guardian

Tethys B

*Leading
Coorbital*

*Trailing
Coorbital*

Inner F Ring Shepherd

Outer F Ring Shepherd

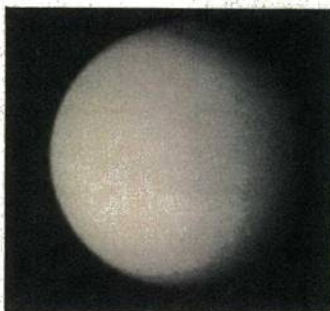
Dione B

Mimas



When Voyager 2 left the saturnian system and headed on to Uranus, our reconnaissance of the ringed planet ended. Though the data are just in months or years of analysis lie ahead, we now know enough about each of the 17 moons and moonlets to move them from obscurity to familiarity. At a glance, saturnian moons — except for Titan and Phoebe — are cratered iceballs that contain a bit of rock. But it doesn't take a much closer look to make their similarities fade and their variations come to the forefront. We now know that each of these satellites has a distinct "personality."

Titan, the smog-shrouded



With a diameter of 5150 kilometers, Titan is one of the largest satellites in the solar system — smaller only than Jupiter's Ganymede and possibly Neptune's Triton. Titan's true claim to fame is that it is the only moon known to have a thick atmosphere.

Titan's density, 1.9 grams/cm³, proves that it contains at least some rock — scientists estimate about 50%. The remainder of its mass is likely to be a mixture of about 44% water ice and 5% or 6% methane ice. The atmosphere consists of 85% nitrogen and 12% argon — methane and a small but important amount of more complex organic molecules make up the other 3%. The pressure at Titan's surface is 1.6 times that of the Earth, and its temperature varies from 93 K at the poles to a slightly warmer 95 K at the equator.

Since Titan shares Saturn's 30-year orbit of the Sun, each of its four seasons is long. But curiously, the times of greatest heating by the Sun — the solstices — are not the times of greatest hemispheric temperature difference. The thermal inertia of Titan's immense atmosphere slows its response — which turns one hemisphere darker and redder than the other and generates banding in the clouds one season later, at the equinoxes.

Despite the sluggish response of Titan's atmosphere, Voyager 2 saw significant changes. During the titanian "week" that passed between the two Voyager encounters, the dark hood over the north polar region became a dark band. Right now, we don't know why.

We can't see directly what Titan's surface is like, but we can theorize. When the methane (CH₄) in the satellite's atmosphere is exposed to ultraviolet sunlight, its molecules lose one or more of their hydrogen atoms. These molecule fragments recombine with other carbon compounds into several different hydrocarbons such as propane, ethylene, acetylene, hydrogen cyanide, and cyanogen. Continued "processing" of these carbon

compounds creates micron-sized smog particles that block our view of the surface.

To test this mechanism for making smog, B. N. Khrae and Carl Sagan of Cornell University performed a laboratory experiment. They sealed a mixture of 91% nitrogen and 9% methane in a large flask and sparked it with an electric arc for four months. At the end, they found a reddish-orange organic deposit on the inside of the flask. While noting that it may not be accurate to extrapolate this to the free-floating gases on Titan, Sagan thinks he and his coworker "may have bottled the clouds of Titan."

Whatever their origin, the smog particles sink slowly through the atmosphere and take about a year to reach the surface. There, scientists estimate, this hydrocarbon "snow" may collect in layers hundreds of meters thick.

Since all the methane in the atmosphere at any one time would be converted to smog particles and precipitated in about a million years if it weren't replenished, there has to be a continual flow of methane into the atmosphere. The most likely source is the surface, where the temperature is just warm enough for methane to exist as a liquid. It would take only a slight rise in heat to "evaporate" some of it into the atmosphere.

Thus, we can picture the surface of Titan as a landscape of dark hydrocarbon sludge dotted with pools, lakes, or even oceans of liquid methane. Overhead would sweep a dull orange sky with a few grey clouds of methane drifting along in a gentle breeze.

Phoebe, the interloper



The most distant of the satellites, Phoebe was encountered by Voyager 2 far out from Saturn on the morning side of the planet. It orbits in an eccentric, retrograde path nearly in the ecliptic plane. Earth-based studies led astronomers to think that Phoebe was

small, dark, ruddy, and probably irregular. In color, it resembled a Trojan asteroid.

Though certainly dark and ruddy, Phoebe is also round, and unexpectedly large — 200 kilometers across. Astronomers made their guesses about size by assuming the surface materials have a moderately low reflectivity. Since Phoebe reflects only about 5% of the light falling on it — considerably lower than expected — their early estimates of its diameter were too low.

The moon's roundness also surprised planetary scientists. Rocky objects of Phoebe's size can maintain an irregular shape indefinitely, and astronomers assumed it would resemble a gigantic shard of rock — perhaps like the captured martian moons Deimos and Phobos. No one yet knows why Phoebe is round, but the answer may lie in systematic differences between "inner solar system" asteroids like Phobos and "outer solar system" asteroids like

Left: The fault valley of Latium Chasma snakes across the crater-strewn face of Dione. The central peak of the 100 kilometer crater Aeneas looms nearby. Battered satellite surfaces like these preserve a history of impacts dating back eons in the history of the saturnian system.

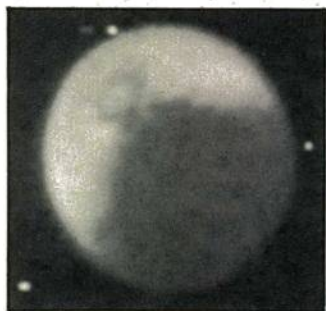
Phoebe.

Though Voyager 2's photos are of low resolution and don't show very much, Phoebe appears to have some *albedo* (brightness) markings, or topography — perhaps a combination of both. Bright areas that could mark fresh impact scars dot one or two areas on Phoebe's surface. These markings helped scientists establish that Phoebe rotates once every 9 to 10 hours.

Because material blasted off Phoebe by small meteor impacts could be swept up by Iapetus, Phoebe has been long considered a possible source for the dark material on that moon. But a spectral survey carried out at the University of Hawaii showed that Phoebe's surface material is more reflective at short wavelengths, and less reflective at long wavelengths, than the dark hemisphere of Iapetus. If other surveys confirm this finding, Phoebe will be ruled out as a source for most — if not all — of the Iapetan black material.

It's unlikely that Phoebe has been with Saturn since the beginning of the solar system. It probably originated elsewhere and was captured by Saturn's gravity. Phoebe may be another Chiron, an asteroid which orbits the Sun between Saturn and Uranus and is thought to be a "dead" comet nucleus. It has nothing in common with the rest of the Saturnian moons: it's rocky; they are icy. Where they orbit close to the plane of Saturn's equator, it orbits at an angle. It is truly an interloper.

Iapetus, the two-faced



The two hemispheres of Iapetus have long presented a very difficult problem to astronomers. The leading side of Iapetus is darker than fresh black asphalt, and the trailing side is as bright as slightly dingy snow. Is Iapetus a dark

moon with a white part or a white moon with a dark part? Because its density is very low, about 1.1 grams/cm³, planetary scientists assume that Iapetus is an iceball with a dirty face. But where did the "dirt" come from?

One solution — that the dirt is Phoebe-dust — no longer appeals to scientists very much. Although no one has yet duplicated the University of Hawaii spectral scan, its measurements seem correct and will probably be confirmed. Moreover, photographs taken by Voyager 2 show that the dark material, whatever it is, doesn't behave as it would were it dust from Phoebe.

The Voyager photos show heavy cratering in both light and dark parts, though those in the light part are easier to see. This suggests that the surface is ancient. Many light craters near the edge of the dark region have dark floors and look as if they've been flooded from below. But the flooding isn't uniform in all craters. In some places, all the craters show more dark material to one side or another — like permanent shadows — as if the dark stuff had been sprayed onto the landscape from above at a very shallow angle. If material had been scattered from the

surface of Phoebe over millions of years, the coating would be far more uniform.

To compound this puzzle, a large dark ring with a light center faces Saturn almost squarely from the equator of Iapetus. Both Voyager 1 and 2 images showed little or no topographic relief in and around this ring. Is it some sort of ring-fault through which black stuff oozed out? Is it a collapse feature? We don't know yet.

This emphasizes the fundamental problem: What produces the inky black material? Iapetus is too cold, too small, and too icy for indigenous volcanic activity. Taking their argument from theories on how the early Saturn nebula formed, some planetary scientists have suggested that the basic model for Iapetus — 60% water ice and 40% rock — is too simplistic. Of all the Saturnian satellites, only Iapetus was far enough from the warm primordial Saturn to retain all its methane as ice. Iapetus might, instead, be 55% water ice, 35% rock, and 10% methane ice.

Adding methane changes the picture entirely. Ultraviolet sunlight falling on methane decomposes it photochemically. The resulting byproducts could recombine into dark hydrocarbon compounds. If methane escaped slowly from the interior of Iapetus over millions of years, these dark compounds could accumulate and stain part of the moon.

But how can this happen only on the moon's leading hemisphere? One scientific hypothesis invokes a planet-wide sheet of frozen methane just underneath the topmost layers of water ice. And, although impacts can hit Iapetus anywhere, more of them occur on the moon's leading hemisphere. Years of bombardment could possibly have scoured off the overburden of water ice and exposed the methane ice layer to blacken in the sunlight.

What's even more intriguing about Iapetus is that all these processes could be going on simultaneously. The moon's surface could easily be a mix of black hydrocarbons with some Phoebe-dust. Moreover, both substances may have been mixed, remixed, and scattered across the surface by subsequent impacts — "gardened" in the scientists' phrase.

Hyperion, the misshapen



Voyager 1 photographed Hyperion from a great distance so its images revealed only that it was somewhat elongated and not very reflective — a typical icy moon. As such, it attracted no particular interest among the scientists. The plans for

the second Voyager encounter called for passing twice as close. This time the photo images proved very interesting.

Right: The surface of Mimas abounds with craters, scarps, and valleys. This photo shows features as small as two kilometers across. The two craters near the right-hand limb are Launcelot and Gwynevere; the valley extending toward the lower left is Ossa Chasma.



Hyperion is an icy moon with a dingy-tan surface layer. It reflects about 30% of the light falling on it. Photographs clearly show impacts of many sizes, both old dark craters and bright new ones. Overall, it has the shape of a nibbled-on hamburger or a bashed-up hockey puck. One end has been knocked off, probably the result of an impact, and other irregularities imply additional larger hits.

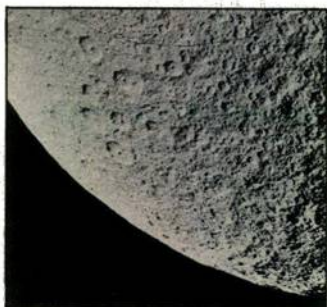
Hyperion's surface appears to be quite old, with craters of all sizes right down to the limit of resolution. When planetary scientists see a heavily cratered surface, they take it as a sign that the surface has been unaltered since the earliest days of the solar system. They know that during the first billion years or so of the solar system's history, the cratering rate was very high. They also know that about 3.5 billion years ago, the rate dwindled sharply as almost all the loose objects were drawn in by the gravity of larger bodies. Since few impacts happen in the solar system now, heavily cratered surfaces have been relatively untouched for eons.

However, the most interesting discovery about Hyperion isn't its shape or topography, but its orbital attitude. Every moon that orbits a large and nearby body will, orbit by orbit, have its spin gradually halted by tidal action from the primary. When the spin has "relaxed" completely, the moon will end up with its long axis pointed toward the primary (the Earth's tidal action did just that to our Moon). Thereafter, the satellite will rotate in the same time it takes to circle the primary — the rotation has become synchronized.

Although Hyperion appears to be rotating synchronously, it is not turned "properly" edge-on toward Saturn — instead, part of its flat surface points at Saturn. Two explanations are possible: one is that Saturn simply hasn't yet had time enough to relax Hyperion's rotation. Relaxation time depends strongly on distance from the primary — the closer the moon, the stronger the tidal effects. At Hyperion's distance, they are weak — so weak in fact that the dynamic imbalance could possibly be primordial.

The other and more interesting idea is that something hit Hyperion recently and jolted it askew. With only weak tidal forces at its orbit, if Hyperion suffered a collision and were knocked out of equilibrium, it would continue to rotate on its tilted axis for a long time.

Rhea, the battered



Rhea has a crater-pocked surface laced with bright wisps. Voyager 1 saw about half of Rhea well enough to show topography, and almost all the rest of it at low resolution. With good Voyager 1 coverage on hand, Voyager 2 ignored the moon.

Although a lot of Rhea's surface looks indiscriminately battered, a closer look reveals at least two distinctly different cratered terrains. One of these is very old: craters upon craters to the point of

saturation, when each new impact destroys as much as it creates. Our Moon's southern highlands are an example of crater saturation.

The other type of terrain has fewer and less distinct craters and shows up in three roughly circular plains on the face that is now turned toward Saturn. These plains may mark where, late in Rhea's early history, three very large chunks slammed into it and gouged out basins. The basins then filled with slush and froze. By the time they had surfaces solid enough to preserve craters, the impact rate was lower and fewer craters were recorded. In addition, all craters except the smallest have flat floors, showing that they, too, have been partially refilled.

Taken globally, Rhea shows hemispheric differences. The leading hemisphere is light and bland, the trailing is dark and has bright wisps. Curiously, cratering decreases abruptly, not smoothly as is expected, from the leading hemisphere to the trailing half of the planet. Scientists think the sudden transition shows that at least two bombardments — one made up of large objects, and one of small — impacted Rhea at different times.

The wisps show up as bright streaks on dark grey patches and tend to form polygonal shapes. Some wisps may be caused by fresh, clean material pushing to the surface through cracks in the crust. Others may be bright rays from late impacts.

Dione, the wispy



Dione is somewhat smaller than Rhea but looks superficially the same. Heavily cratered terrain dominates and is apparently overlain with wispy streaks of bright material. The chief difference in the two satellites, though, is Dione's 2:1 contrast

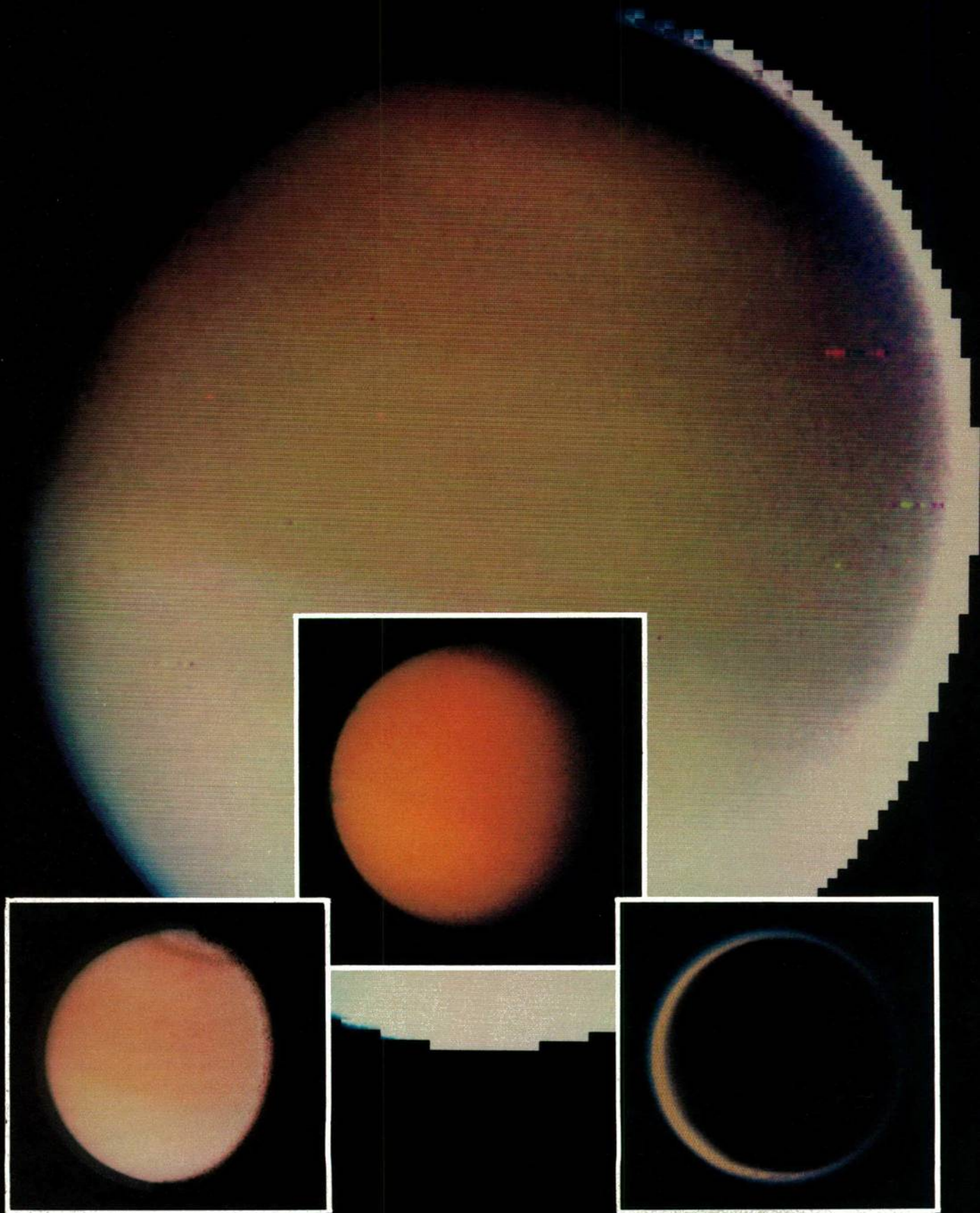
between its light and dark surfaces. This is greater than on any other body in the saturnian system — except, of course, Iapetus.

The satellite is also hemispherically asymmetric, as are many of Saturn's moons. Its leading hemisphere is 50% reflective — much brighter than its trailing side which reflects between 30% and 35% of the light that reaches it. Dione's bright wisps are even more reflective — 60% to 70%. They are probably water that migrated to the surface along fault lines and now appears as white as frost or snow.

The largest feature on Dione is an oval white spot named Amata that lies near the center of the trailing hemisphere. Amata may be just an albedo feature or it could be a large impact crater surrounded and filled with bright deposits of fresh ice or frost.

Although only about a fourth of Dione has been photographed to "topographic resolution," its

Left: Ithaca Chasma — the great crack on Tethys — arcs along the limb of the moon. Scientists think it happened when Tethys froze to a great depth and expanding ice split the upper crustal layers apart. Since impact craters pock the crack, the split must have occurred long ago.



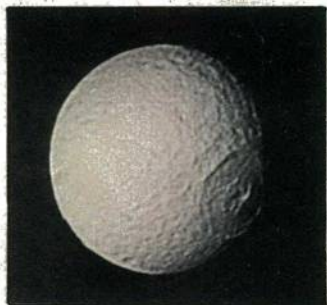
surface still hints at two cratering episodes. The more heavily cratered and presumably older terrain sports larger craters than the younger terrain. Though we can't tell yet if the younger surfaces occur mainly in circular patches (as they do on Rhea), scientists believe that parts of Dione have also been resurfaced and then cratered again by impacts.

Except for the smallest, Dione's craters tend to be shallow and have flat floors — much like the craters on Rhea. This suggests that the heat of impact melted the icy material making up the moon, which then flowed and filled in the bottom of the crater. Some slumping of rubble may also have occurred, but the surface gravity on a 1000 kilometer iceball is pretty low.

Dione also features distinct systems of valleys. Appearing as long, slightly sinuous troughs, these chasms break up into crater chains in certain areas. As faulting produced these valleys, it probably released volatiles that puffed out here and there and created small, round vent holes.

Dione's longest valley, Palatine Chasma, traverses a fourth of the satellite from its high southern latitudes northeasterly onto the trailing hemisphere where it merges with a bright streak leading toward Amata. Unfortunately, the resolution of the photographs isn't good enough to show whether the two merge or if the valley changes character in some way.

Tethys, the cracked



With the exception of Enceladus, no saturnian moon is as bright as Tethys. Its "dark" region — situated on the leading hemisphere — has a reflectivity of 60%; the bright regions go as high as 80%. Tethys's density, 1.0 grams/cm³, confirms that it is an iceball.

The satellite's face shows a multitude of scars from impacts ranging from a mammoth crater — 400 kilometers across — down to those barely visible at the 2 kilometer resolution of the best Voyager 2 photos. Smaller craters probably exist beyond the limit of Voyager's resolution. The 400 km crater has a massive central peak inside and several concentric ring-scarps outside the main wall. The central peak piled up as the ice rebounded after impact; the scarps formed when ice blocks settled back toward the impact site along shattered fault planes.

Voyager 2 caught a view of this crater when it lay on the limb of the moon. The crater floor is convex and matches the curve of Tethys. Evidently, Tethys was warm enough after the hit for material to flow out and "heal" the yawning hole in its side.

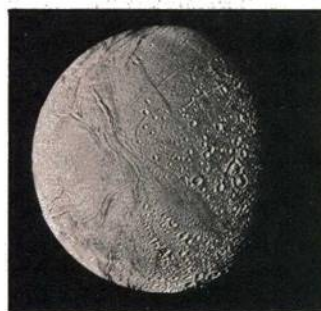
Left: Blandly orange at first glance, Titan's atmosphere shows more detail when images are enhanced. At top, a specially processed photo reveals subtle differences in the northern hemisphere clouds. (The stepped edge is a processing effect.) At bottom, images show (left to right) the north polar band, the darker northern hemisphere, and a backlit shot displaying a crescent Titan with blue atmospheric hazes.

But Tethys has even a more impressive feature: a gigantic valley that encircles three-fourths of its circumference. It's natural to suppose that the big crater and the valley are the result of the same "geologic" force, but scientists now believe the two are unrelated.

What caused the crack? We can find the answer by examining Tethys' composition. Almost pure ice, the young Tethys would have been little more than a soggy slush ball. As the moon cooled, the outside froze first, forming a rigid skin of ice over the molten interior. As the chill crept deeper into the moon, its insides reached the freezing point and — just as an ice cube does — expanded slightly. The stress proved too much for the brittle surface layers and — CRACK!

The expansive valley must have formed long ago. Theory suggests that Tethys would have cooled fairly rapidly. This idea is strengthened by photographs of the valley floor which reveal a few craters — relics of a moderate cratering rate higher than at present, but lower than that of the earliest days.

Enceladus, the smooth



Enceladus was the "surprise package" for Voyager 2. Voyager 1's lower resolution photos showed only that the surface had a few features, very low relief, and was extremely bright — almost 100% of the light falling on it bounces off. Like Tethys, its

density is low (1.2) and the moon is made largely of water ice. Voyager 2's close-up photos show that Enceladus has several types of terrain on a very smooth surface — especially in comparison to its cratered and scarred neighbors, Mimas and Tethys.

Scientists discern three main types of terrain on Enceladus: moderately cratered, lightly cratered, and grooved plains. Yet each of these has variations within it. The ropy, grooved plains, for example, are grooved and faulted in some places and grooved, faulted, and cratered in others. Some moderately cratered locations have many small craters, but in others, larger impact scars predominate.

One glance at the sparseness of pits on Enceladus tells you that either the moon has miraculously avoided impacts from the types of objects that smacked its neighbors so thoroughly — or that some process has erased the marks.

By counting the craters of each size and comparing their number with the amount on other known surfaces, planetary astronomers can determine the "exposure time" — how fresh a surface is. The uncratered, grooved plains on Enceladus cannot be more than 100 million years old and even its most battered regions are scarcely as old as the youngest on Dione.

Because cratering dates back much further, the entire moon has been resurfaced at least once and in some places even more often. The ground between the craters in even the most battered regions is still basically a flat plain, with none of the crazy-quilt

Moon	Orbital Distance		Orbital Period (Days)	Diameter (km)	Density (gm/cm ³)	Albedo	Mass x10 ²³ g
	(km)	R _S					
A-Ring Guardian	137,700	2.28	0.6012	80x60x40	—	40%	—
Inner Shepherd	139,400	2.31	0.6130	140x100x80	—	40%	—
Outer Shepherd	141,700	2.35	0.6285	110x90x70	—	40%	—
Trailing Co-Orbital	151,400	2.51	0.6943	140x120x100	—	40%	—
Leading Co-Orbital	151,500	2.51	0.6947	220x200x160	—	40%	—
Mimas	185,600	3.08	0.9424	392	1.2	60%	0.38
Enceladus	238,100	3.95	1.3702	500	1.2	100%	0.84
Tethys	294,700	4.88	1.8878	1050	1.2	60%/80%	7.55
Tethys B	294,700	4.88	1.8878	34x28x26	—	50%	—
Tethys C	294,700	4.88	1.8878	34x22x22	—	50%	—
Dione	377,500	6.26	2.7369	1120	1.4	50%/30%	10.5
Dione B	378,100	6.27	2.7369	36x32x30	—	40%	—
Rhea	527,200	8.74	4.5175	1530	1.3	60%	24.9
Titan	1,221,600	20.25	15.9454	5150	1.9	20%	1345.7
Hyperion	1,483,000	24.58	21.2767	360x210	—	30%	—
Iapetus	3,560,100	59.01	79.3308	1450	1.2	5%/50%	18.8
Phoebe	12,950,000	214.7	550.33	200	—	5%	—
Luna	—	—	—	3476	3.3	7%	735

Inclination of Orbit	Orbital Eccentricity	Magnitude from Earth at Opposition	Year Discovered	Discovered by	
0.3°	0.002	17	1980	Voyager 1	icy composition; keeps outer edge of A ring in place; temporary name 1980S28
0.0°	0.003	16	1980	Voyager 1	icy composition; elongated; bumpy surface; pushes F-ring particles outward; temporary name 1980S27
0.05°	0.004	16	1980	Voyager 1	icy composition; cratered surface; pushes F-ring particles inward; temporary name 1980S26
0.34°	0.009	16	1966	Dollfus/ Fountain/ Larson	icy composition; bumpy surface; irregular shape; temporary name 1980S3
0.14°	0.007	15	1966	Dollfus/ Fountain/ Larson	icy composition; cratered surface; potato shape; temporary name 1980S1
1.52°	0.019	12.9	1789	Herschel	130 km crater near center of leading hemisphere; many trenches and bowl-shaped craters; icy surface
0.0°	0.0044	11.8	1789	Herschel	smooth, fresh, icy surface; ropy, grooved terrain; few craters; young features
1.1°	0.000	10.3	1684	Cassini	long valley circles three-fourths of moon; 400 km crater; darker leading hemisphere; icy surface
—	—	19	1980	Lunar & Planetary Lab.	round and smooth; icy composition; orbits at L ₄ point; temporary name 1980S13
—	—	19	1980	Wide Field Planetary Camera Team	oblong and smooth; icy composition; orbits at L ₅ point; temporary name 1980S25
0.0°	0.0022	10.4	1684	Cassini	leading hemisphere brighter, but trailing has bright wisps; 200 km bright spot; several systems of valleys; icy surface
—	—	19	1980	Laques/ Lecacheux	one crater visible; icy composition; orbits at L ₄ point; temporary name 1980S6
0.35°	0.001	9.7	1672	Cassini	crater-saturated terrain and three areas of low crater density; a few bright wisps; icy surface
0.3°	0.0289	8.4	1655	Huygens	orange photochemical smog in cold massive nitrogen atmosphere hides probable icy surface
0.4°	0.1042	14.2	1848	Bond/Lassell	eccentric orbit; irregular shape; dirty ice surface; orbital attitude out of equilibrium with Saturn; heavily cratered
14.7°	0.0283	11.9/10.2	1671	Cassini	leading hemisphere very dark, trailing bright; many craters; icy surface
150.1°	0.1633	16.5	1898	Pickering	eccentric, retrograde orbit; rotates in 9-10 hours, unlike all the others which rotate synchronously; rocky composition; dark surface with few markings
—	—	-12.7 10.5 (at Saturn)	—	—	heavily cratered with basalt plains on Earth-facing hemisphere; rocky composition

patchwork of craters and crater remnants that we see on Dione, Rhea, and Tethys.

But how can an iceball like Enceladus dredge up enough warmth to soften and melt away the scars of repeated impacts? Since the moon is too small to have retained the primordial heat of its formation, the source of the warmth must lie elsewhere. We can find the answer by studying the moon's orbit.

Enceladus' circle around Saturn is kept eccentric by periodic gravitational tugs from Dione. As the satellite's path swings it closer and then farther away from Saturn, the tidal force of the planet alternately gives the moon a squeeze and then lets it relax. This creates friction and heat in Enceladus — heat sufficient to soften, even liquify, its ices and thus "repave" parts of the surface from time to time. Since the resonance between Saturn, Dione, and Enceladus is stable, this tidal flexing will continue indefinitely. Enceladus was an active moon — and probably still is today — though nowhere near as active as the jovian moon Io.

Although it lacks the sulfur volcanos of Io, Enceladus may have its own volcanos that erupt water. Saturn's E ring — a wide but thin and tenuous sheet of icy particles — circles the planet in a swath that straddles Enceladus' orbit. The density of particles in the E ring varies with their distance from Saturn and reaches a maximum at the orbit of Enceladus. Could these ice particles have formed from water spewed out by volcanos on Enceladus? It's possible, but we don't know for sure.

Mimas, the lucky



How else can you describe the survivor of an impact great enough to leave a crater a third the moon's own diameter?

As befits an object orbiting close to the outer edge of the rings, Mimas' topography is greatly cratered. Impacts

range from the above mentioned 130 kilometer crater Herschel, almost at the center of the leading hemisphere, down to tiny pits at the limit of resolution.

Diminutive Mimas is weakly cohesive — the gravity at its surface is only $1/200$ that of Earth. Therefore, any impact will blast material out and away. With little rubble falling back and with small chance of fresh material welling up from a cold interior, craters on Mimas tend to be deeper and more bowl-shaped than those on other moons.

The chief exception to this is Herschel — about as large an impact as Mimas could have suffered and survived. Its walls are about 5 kilometers high, and parts of its floor descend 10 kilometers. Herschel's central peak, 6 kilometers high, measures about 25 kilometers across the base. Several other large craters exist, all with flat, partially filled-in floors. By the evidence of the in-fill, these impacts must have either melted some of the moon locally or punched through to a still-warm interior deep below. Without a more

accurate estimate of when the severe impacts occurred, it's hard to say which process dominated.

Many short valleys wind across the surface of Mimas: troughs perhaps 80 to 100 kilometers long, 10 km wide and 1 km to 2 km deep. These may be cracks opened by the shaking that must have accompanied the Herschel impact, or gouges made by planetary shrapnel.

The "Rocks"



In addition to nine principal moons, Saturn controls at least eight smaller satellites. Deceptively nicknamed "rocks" from their irregular appearance, they are actually icy bodies — though all may harbor small rock cores or a scattering of rocky bits throughout. Some have a few craters, but most appear blandly bumpy at the resolution of the Voyager photos.

The A-ring guardian is an oblong shard with no visible markings. Its tiny gravitational force prevents material at the outer edge of the A ring from drifting farther out and keeps the rest of the ring system in place.

The inner F-ring shepherd is also oblong but appears to have a few small craters. The outer moon is fairly round in shape and shows one clear crater on its generally soft-contoured surface. The inner drives F-ring particles orbiting outside of it farther away: the outer pushes ring particles closer in. The outer shepherd has an orbital resonance with Mimas that keeps it in its place. The F ring stays within narrow bounds because of this "gravitational focusing".

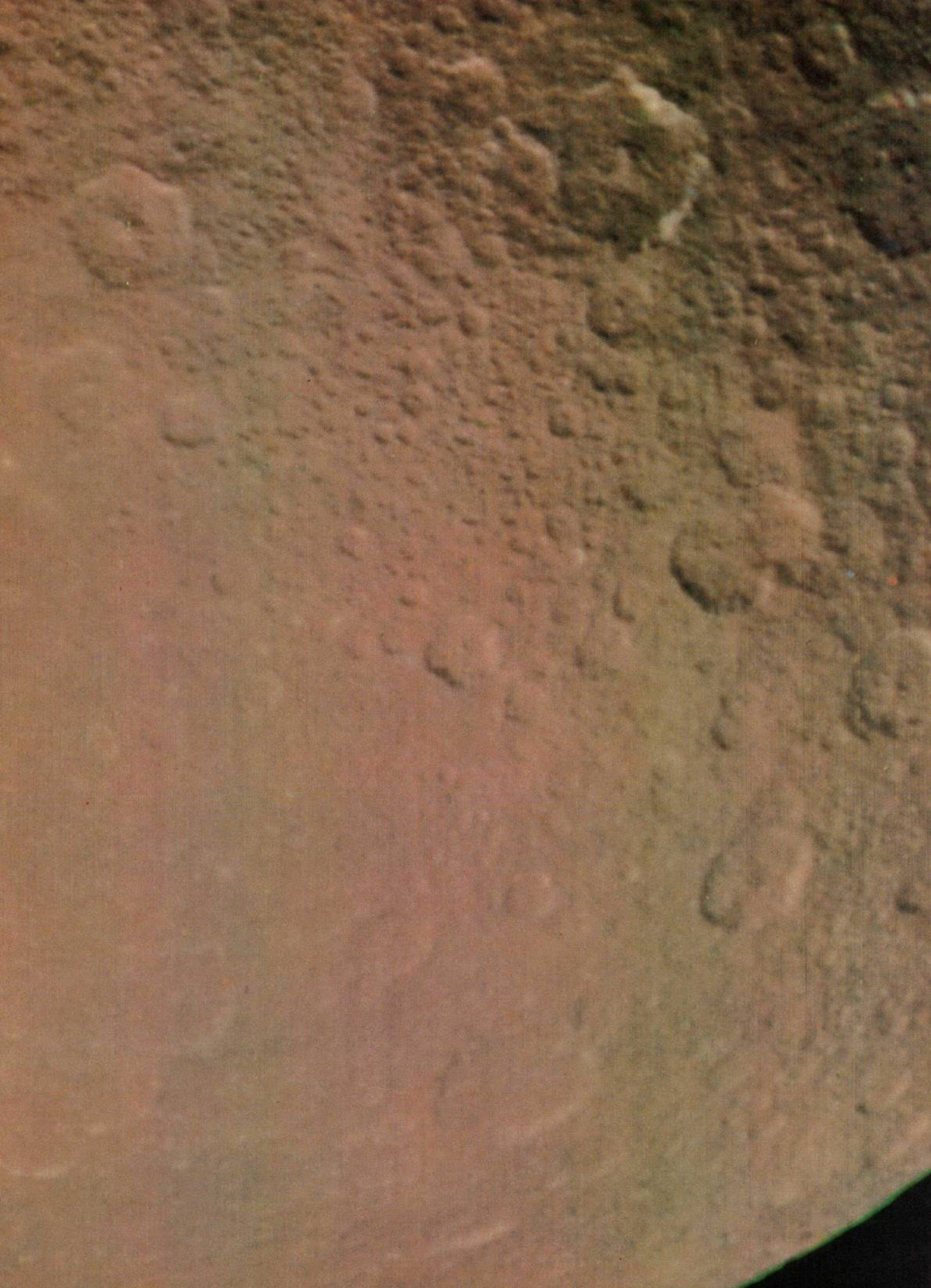
Both co-orbitals, the largest of the "rocks," have several obvious pits and many additional dents that might be eroded impacts. Planetary scientists suspect these two were once one larger moon that broke up — a "Mimas" that didn't survive its "Herschel."

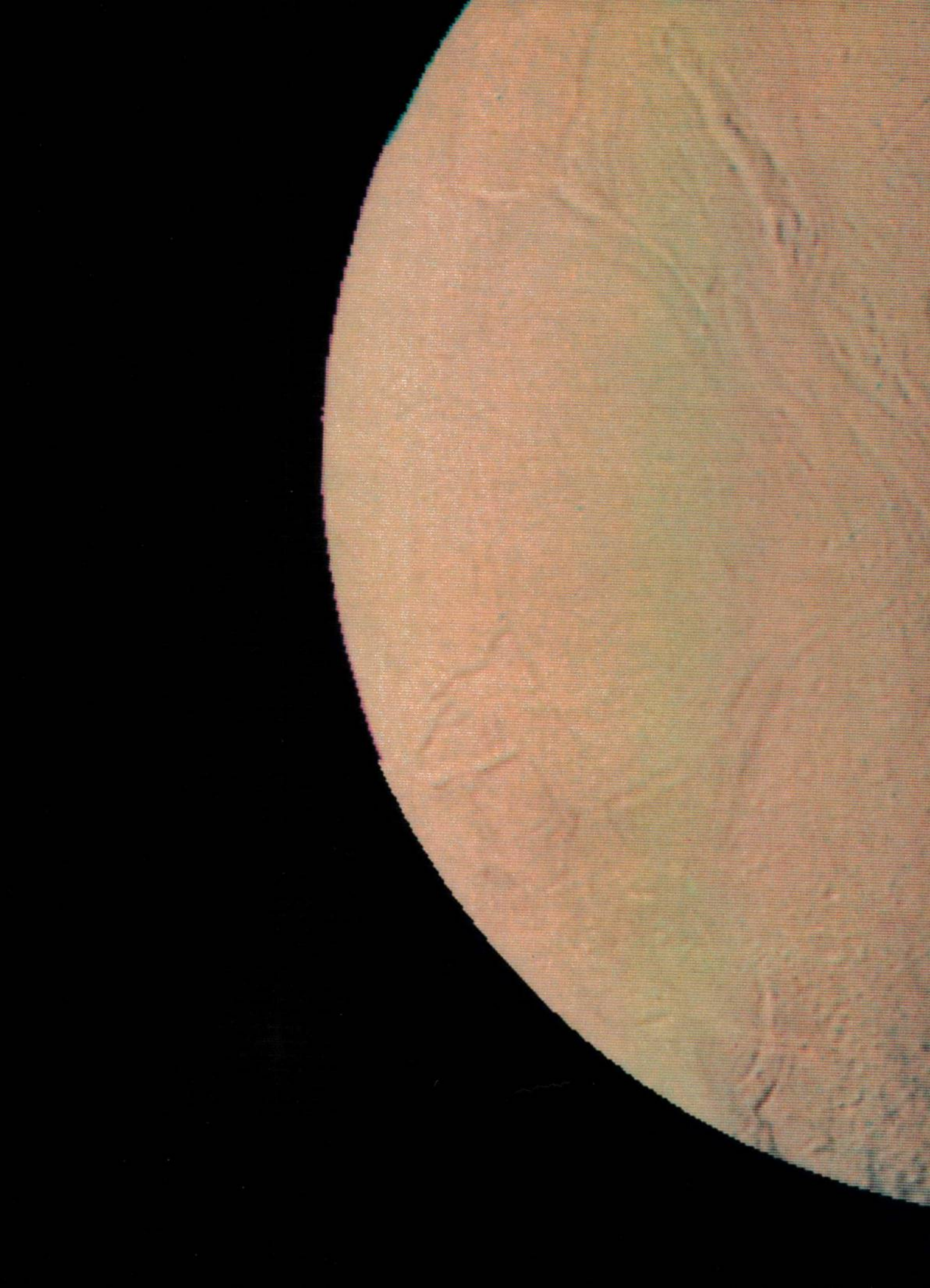
The orbital motion of these two moons is just as fascinating as their apparent history. To understand what happens, let's assume for a moment that we are standing on one of the two — moon A. As we make orbit after orbit around Saturn, the other moon, B — on a slightly lower and slightly faster orbit — will appear to pull ahead of us slowly. After we have circled Saturn many times, we'll see moon B gaining from behind.

But before B can "lap" us, moon A will be affected by B's gravity. Our moon will switch into the closer and faster orbit and slowly pull away from

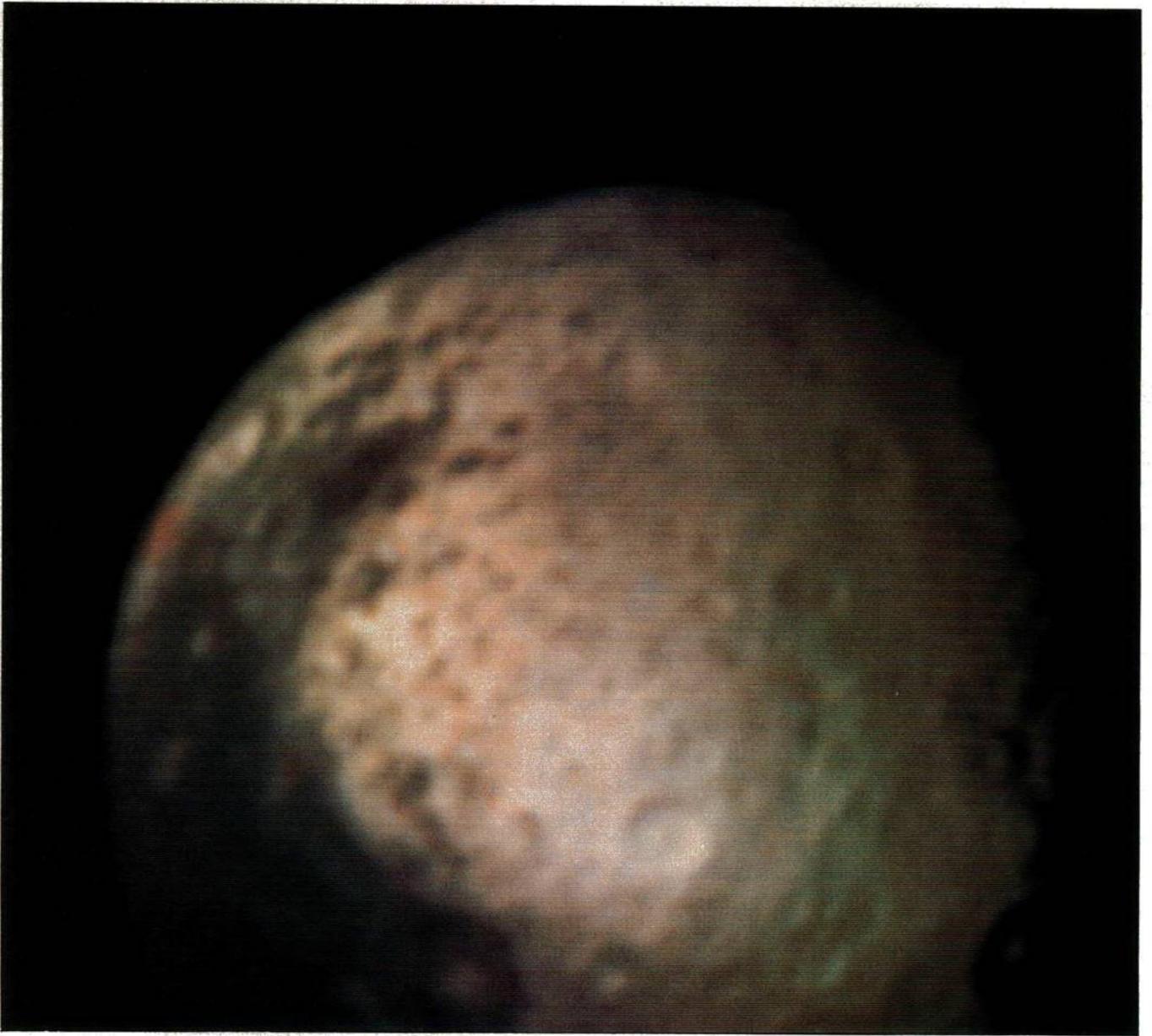
Right: This heavily cratered surface on Rhea probably dates back to the formation of the solar system — 4.5 billion years ago. The white areas on the rims of craters may be fresh ice exposed by slumping.

Overleaf: The surface of Enceladus shows many contrasts plus signs of recent tectonic activity. Old cratered terrain alternates with younger cratered regions and even younger grooved and faulted plains.









moon B. Meanwhile, moon B will move into the higher and slower orbit formerly used by moon A. From our standpoint, of course, it looks as if moon B has come up from behind, slowed, and fallen back again. Eventually our speedier orbit will bring us to the point where we are about to overtake moon B. At that time, our moon perturbs B into the closer and faster orbit, and is moved back into the higher and slower course. Then the cycle begins again.

Tethys has two companion moons, Tethys B and C, that share its orbit. Celestial mechanics have long known of certain orbital positions, named *Lagrangian points*, where the gravitational effects of a primary planet, its moon, and any object tiny enough to have a negligible gravity field of its own would all balance.

Although five Lagrangian points are theoretically possible, only two are stable in a real planetary system — perturbations by other system members will soon disrupt the precarious balance at any of the other three positions. The two stable places lie 60° ahead (L₄) and 60° behind (L₅) a moon in its orbit around a primary. Lagrangian points also exist for the planets themselves, with the Sun as the primary body. Jupiter has two collections of small asteroids: one 60° ahead of it in its solar orbit and one 60° behind. These are called the Trojan asteroids, because the first one found was named Hektor.

The two moonlets that wandered into Tethys' Lagrangian points and remained there are small. The Lagrangian leading moon is round and appears featureless; the trailing is oblong and equally undistinguished. They are probably chunks of ice.

Dione also has a Lagrangian moon, Dione B, but unlike the Tethys system, has no satellite in its trailing position. Voyager's cameras searched for a "Dione C" but didn't find one. Small and round, Dione B shows at least one large crater. Dione's Lagrangian satellite makes a curious comparison with the pair in Tethys' orbit. Those of Tethys stay very close to the actual L-points, never wandering more than a degree or two of orbital longitude from it. By contrast, Dione B strays back and forth in the orbit by as much as 14°, yet it too will remain with Dione indefinitely — demonstrating the stability of these two L-points.

Putting It Together

Saturn's nine moons and eight moonlets each have similar characteristics, but each is also a distinct planet. What can we learn of their past from the way all of them look and behave today?

The current model for the early history of the solar system calls for the planets to condense out of a thick nebula of gassy dust that surrounded the early Sun. The temperatures in the nebula, which decrease farther away from the Sun, largely determine the nature of any object that forms from the nebular material at a given distance. Thus, near the Sun, rocky terrestrial planets formed from iron and silicates,

Left top: Looking down on the northern hemisphere of Iapetus, we see a landscape of craters including a bright and fresh impact scar. **Bottom left** is misshapen Hyperion, the survivor of many impacts. **At bottom right**, the inner of the two F-ring shepherd satellites and the ring itself are silhouetted against Saturn.

which condense at high temperatures. Even the small bodies, fragments that became asteroids, were rocky.

Farther out where the nebula was cooler, the volatile elements were not driven away. Jupiter and Saturn formed from hydrogen, helium, and other materials in mixtures of gas like that of the Sun. This outer part of the solar system was also filled with many icy planetesimals — objects too small to be planets.

As time passed, the planets exerted their gravitational effects and began to clear the solar system of its planetesimals. Those in the inner system — fewer to begin with — were swept up quickly; today, the ancient faces of Mercury and the Moon show the scars of this bombardment at the end of their accretion. In the outer system, some planetesimals were thrown into orbits that took them far away — as much as half a light-year from the Sun — where they formed the *Oort Cloud*, named after the astronomer who predicted its existence. At intervals, a planetesimal in the cloud will begin its slow fall back toward the Sun, perturbed perhaps by a nearby star's gravity or by random motions. When these planetesimals reach the inner solar system, they glow brightly. We call them comets.

However, not all of the outer system's planetesimals went into the Oort Cloud. Many were swept up, adding mass to the gas giant planets and scarring the faces of their solidly surfaced moons.

But there is a nagging puzzle. Why is Saturn's satellite system so different from Jupiter's? The jovian system has four large moons — progressively less dense as they grow more distant — and a large number of others, probably captured. Since Jupiter was hot when its satellites formed, it's natural to expect the icy fractions of the inner moons to be "roasted" out. Farther from Jupiter, moons with a larger proportion of ices could form.

But Saturn has only one large moon and a host of smaller ones — all icy. (Phoebe doesn't count because it probably formed elsewhere and was captured.) Moreover, Saturn's system huddles much closer to the planet than does Jupiter's, so its moons ought to show a strongly temperature-controlled grading. But they don't — why?

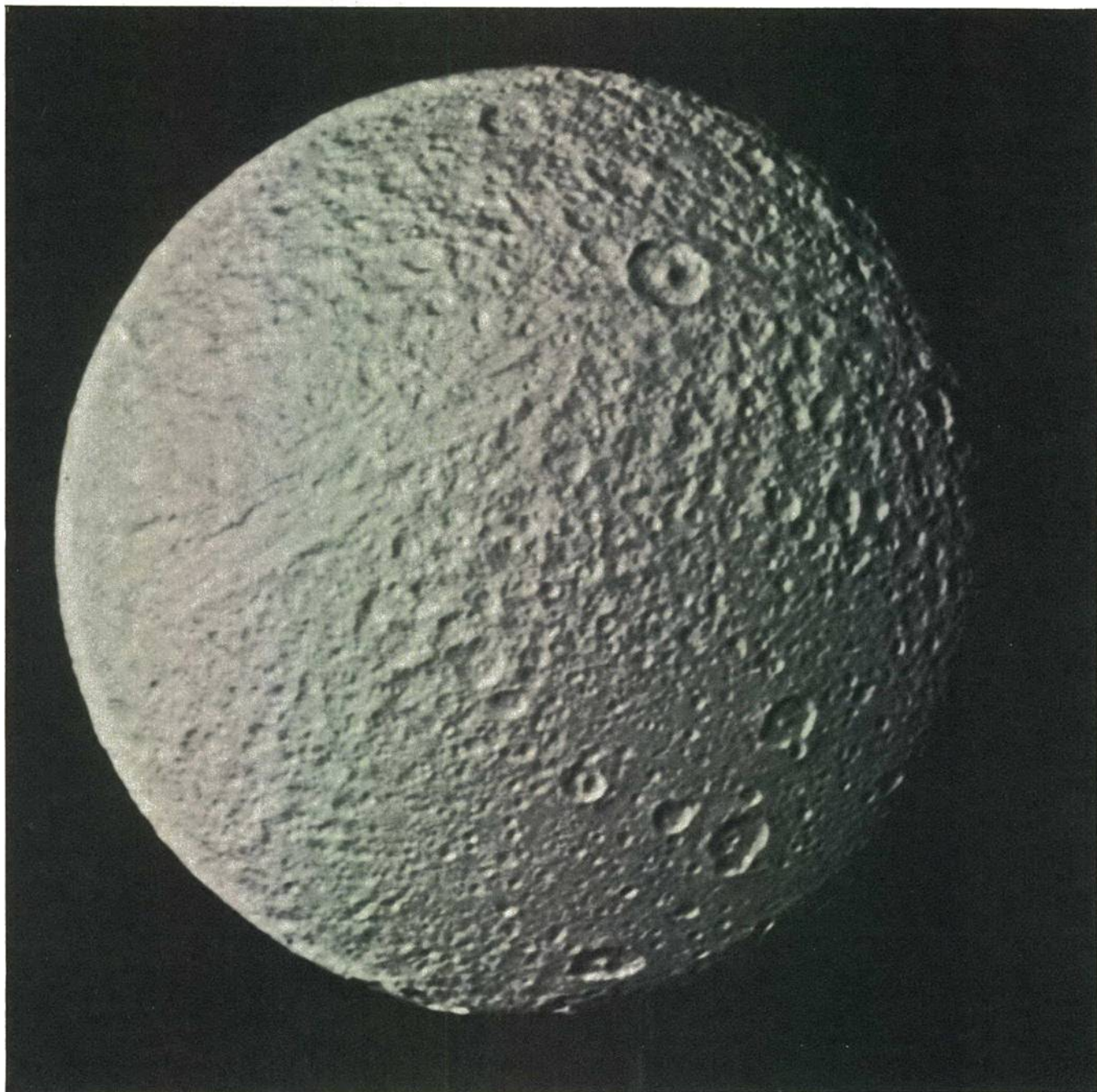
Eugene Shoemaker of the U.S. Geological Survey

Voyager 2 Photo Data

For each picture shown on these pages, the table below gives the mission and the distance from Voyager to the subject. The picture number is NASA's designation and specifies the image in their files.

Page	Mission	Range (Km)	Picture #
Cover	V2	119,000	P-23955
8	V1	162,000	P-23113
11	V1	129,000	P-23112
12	V2	594,000	P-23948
14 top	V1	—	260-1166
14 left	V2	2,300,000	P-24067
14 center	V2	4,500,000	P-23929
14 right	V2	907,000	P-23949
19	V1	128,000	P-23208
20/21	V2	119,000	P-23955
22 top	V2	1,100,000	P-23961
22 left	V2	500,000	P-23936
22 right	V2	1,200,000	P-23954

All photographs courtesy of JPL and NASA.



This view of Tethys shows two terrains: a greatly cratered region — with Ithaca Chasma extending through it — and a smoother and younger area to the lower right. The less cratered region was "resurfaced" by internal activity at some point in Tethys' past — after the heaviest bombardment ceased.

has an idea — admittedly almost pure speculation. He thinks the saturnian moons we see now are the remnants of an earlier moon system that was bashed to bits by planetesimals. If Saturn once had a whole set of "Titans" broken up by massive impacts, most of the denser parts of them would have been captured by Saturn itself. The lighter parts — the ices — could have reaccreted into the moon system we have now. According to this model, the rings are fragments that never reassembled because they lie within range of Saturn's disruptive tidal forces. Why didn't this happen at Jupiter? Planetesimals were more

abundant near Saturn than at Jupiter because it was colder.

And Titan? Since the Greeks honored the mythological Titans as the inventors of arts and magic, it's only appropriate that Titan alone, of all the early saturnian moons, should have survived.

Whatever bizarre histories we construct for Saturn and its system, the truth is probably far stranger. With a long gap in planetary exploration ahead of us, the data from the Pioneer and Voyager reconnaissance will be all we have to work with. Yet our theories — simplistic as they may seem 100 years from now — will help scientists design more advanced missions to Saturn. And possibly then we will have a true understanding of how this beautiful planet and its fascinating system of rings and moons came to be.

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ASTRONOMY FORUM

The Planetarium: A Cultural Dinosaur?

Your friendly neighborhood planetarium is in trouble. That wonderful domed theater where you went as a child to see the stars come out on rainy days and to follow a bouncing arrow from constellation to constellation may be rotating toward oblivion.

One thing is certain: the world which welcomed the first planetarium in the early 1920s was a very different world from the one we live in now. So our search for the origins of the difficulties facing today's planetariums should begin back there — in post WWI Germany.

The incipient planetarium has been skillfully documented in Henry C. King's *Geared to the Stars*, Helmut Werner's *From the Aratus Globe to the Zeiss Planetarium*, Heinz Letsch's *Captured Stars*, and Harriet Lattin's *Star Performance*, which can be borrowed from your local library or university. The essential fact to be drawn from these books is that the planetarium has two obvious parents . . . the celestial globe and the mechanical model solar system, or orrery — named after Charles Boyle, fourth Earl of Orrery, for whom the first one was made. Celestial globes display on a spherical surface — as do their terrestrial counterparts for geographical elements — the location of celestial bodies and configurations. Mechanical model solar systems can be either simple or elaborate devices that show the positions and motions of the planets and, sometimes, some of their moons. Many schools have working models; antique versions can be found in museums and private collections.

These two parents of the modern planetarium were married early this

century at the Carl Zeiss optical works in Jena, Germany. The result was a strange-looking machine that used projection techniques to display on a fixed, overhead dome/screen the stars of the night sky, the Sun, Moon, and classical planets, and their apparent motions caused by the rotation of the Earth or the Earth's motion around the Sun. When the device was first demonstrated in August 1923, on the roof on the Zeiss factory, it was dubbed "The Wonder of Jena" and people traveled from many parts of Europe and beyond to see it operate. In the official patent records of Germany, it is called the Zeiss projection planetarium.

Professor Charles Hagar of San Francisco State University, writing in



the June, 1969 issue of the Pacific Planetarium Association newsletter *The Pointer*, gives us an amusing but accurate account of how the early Zeiss projection planetariums were used. Virtually everything the machine can do is included in this summary:

"People entered the planetarium chamber (I hesitate to call it a theater at this point) and, while waiting for the arrival of the lecturer, they sat in awe of the mechanical marvel . . . The Wonder of Jena . . . in the center of the room. Sitting before the visitors like a creature from another world, the planetarium demanded the respect of the mere earthlings who had come to pay homage. After some minutes of being mesmerized by the projector,

"Herr Professor" arrived and ascended the podium.

"During the hour that followed, the earthlings were to become bystanders to a cosmic duel between the lecturer and the creature at the center of the room, each trying to outdo the other in the number of astronomical facts and motions that could be crammed into the hour. The projector would twirl and exhibit amazing astronomical contortions to impress the earthlings with its mimicry of diurnal motion, annual motions, polar altitude, and precession. The Moon would flash through its phases; the Sun would slide up and down a meridian showing perpetual noon; the earthlings would be taken to the Arctic Circle to watch the midnight Sun; they would descend to the equator where they would be treated to the Southern Cross and the Clouds of Magellan. In the meantime, the lecturer would be pouring forth, in encyclopedic fashion, the number of miles . . . er, kilometers . . . to the Moon, the Sun, Jupiter, and the nearest star. As the stars whirled circumpolar, he would point out the constellation figures of Ursa Major and Ursa Minor. The arrow, like a demented moth, would dash from star to star, finally spiraling horizonward in a series of dizzy loops. The earthlings would be asked to keep one eye on the rising Moon and the other on the setting Sun!

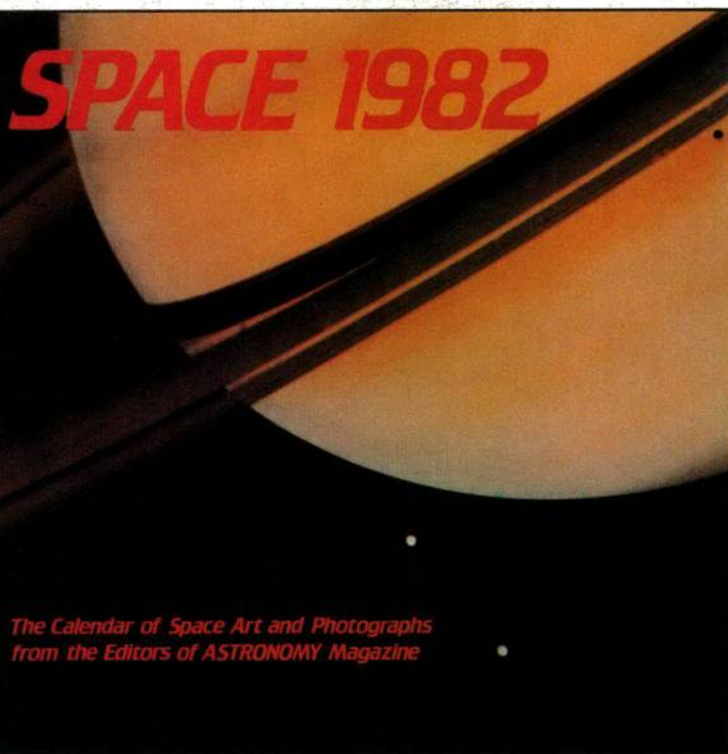
"All of these celestial gyrations and streams of astronomical facts would be punctuated by lantern slides . . . some right-side up, some upside down. The same slides were used every month, but the sequence was changed to add an element of 'drama!' The usual standard assortment included Moon phases, seasons, relative sizes of planets, a diagram of celestial sphere with an

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astronomical triangle (the lecturer always spends about fifteen minutes explaining this one) and, finally, the traditional picture of the Full Moon.

"Then, all of a sudden, the stars would be clicked off and the house lights on. As eyeball pupils quickly contracted, Herr Professor would say 'Thank you!' The earthlings would pull themselves together, stretch their necks and wiggle their heads. Snapping sounds ricocheted around the audience as neckbones snapped back into place. Now, sitting up straight in creaky chairs, they would give Herr Professor much applause! In response to this he would bow, first in the direction of the projector, then toward the earthlings. A click of the heels, a smart turn, and the exit was accomplished. Earthlings left. Lights were extinguished. Doors shut. The creature was left in its dark cave until the next day, when lights would again waken it, and Herr Professor and the projector would once again engage in their cosmic duel before a group of admiring earthlings."

A trifle exaggerated, perhaps, although from time to time people report having seen very similar presentations today. Keep in mind also that it was in settings like this that a number of the men who were later to provide the funds for the establishment of major planetariums on this continent had their first planetarium experience.

Back in the 1920s, when the Zeiss projection planetarium was introduced, there was no such thing as television. Even radio was still a new diversion. No multi-media shows existed as we understand the term, and certainly no Cinerama, Cinemascope, IMAX, or Dolby sound. Movies came in two colors — black and white — and they were shown on tiny flat screens. They were also as silent as the night sky. Into that age came the planetarium. Its giant hemispherical dome, and its capacity for surrounding audiences with visual imagery, seemed to bring the entire universe within 50 feet of the audience. No wonder people were excited.

The first planetarium installed in the western hemisphere was the Adler in Chicago — it was built in 1930. A number of Americans who were impressed either directly or indirectly by the spectacle of the European planetarium provided the funds that allowed several large cities in the United States to build and operate public planetariums. Significantly, their names gleamed in brass over the doorways — not the name of Zeiss. Among the others set up during that period were the

Hayden in New York, the Fels in Philadelphia, the Buhl in Pittsburgh, and the Griffith in Los Angeles. During this period, the word planetarium came to represent more than a machine. It now denoted the entire building in which the machine was located.

Then, in the late 1940s, a reconditioned pre-war projector enabled the University of North Carolina at Chapel Hill to open the Morehead Planetarium. The Boston Museum of Science and the California Academy of Sciences in San Francisco arranged to have custom-made projection planetariums designed and built for them.

But the greatest single development in planetariums during this period was the Spitz projector. Armand Spitz, who had been both a newspaperman and a lecturer at the Fels Planetarium in Philadelphia, was to earn the title of "The Henry Ford of Planetariums" because of his invention and the subsequent marketing of a small, inexpensive star projector. Spitz's timing was perfect. A few years later, thanks to the scare given to the country when

The planetarium doesn't go very far toward describing the universe as it was known in 1923, let alone in 1981

the Soviets launched Sputnik 1 in 1957, there was a new emphasis on training and education in the physical sciences. Federal government funding was made available to assist with the establishment of planetariums at colleges and high schools. Before long, the number of planetariums in the United States had passed 500.

In Canada there was another stimulus to planetarium building. The country marked its 100th birthday in 1967, and towns, cities, and provinces looked for lasting monuments to commemorate the occasion. Until then, Canada had had only one major public planetarium — The Queen Elizabeth in Edmonton which had opened in 1960 and marked the visit of the Queen in the previous year.

There was a surge in planetarium building. Calgary, a city south of Edmonton, decided to build one as its centennial project. Colonel R.S. McLaughlin donated the funds for a planetarium to the Royal Ontario Museum in Toronto. The Dow Brewery donated a planetarium to Montreal. And the Bronfman family, holder of the Seagram's spirits

fortune, set aside funds for a planetarium in Manitoba. The roster of Canadian planetariums was completed when lumber baron H.R. MacMillan donated one to his home city of Vancouver. By the end of 1968, Canada — which had only one operating planetarium in 1966 — now boasted six of the world's most modern.

Indeed, 1968 was a significant year for the development and future of planetariums. In addition to the new Canadian planetariums, the Strasenburgh in Rochester, New York, presented its first shows. Manned space flight also pushed along the public's interest in the cosmos that year as the first spacecraft circled the Moon. And 1968 saw the release of Stanley Kubrick's new motion picture *2001: A Space Odyssey*. In the long run, this film had the most lasting effect on planetariums, because it displayed for the first time the potential of the motion picture to deal with the vastness and beauty of space. Suddenly, astronomical special effects were no longer the exclusive preserve of the planetarium.

Let's keep in mind, now, what projection planetariums can and can't do. Essentially, they are celestial sphere simulators. They show the sky as we see it with our eyes alone under ideal conditions. They show the apparent motion of the sky that is caused by the rotation of the Earth and the seasonal changes in the sky caused by the Earth's journey around the Sun. They show the Sun and the Moon and their motions, and the five classical planets and their motions as viewed from Earth. They can overlay a few coordinate lines and constellation pictures. And that's about it.

In other words, the planetarium doesn't go very far toward describing the universe as it was known in 1923, let alone 1981! By itself, the projection planetarium can add nothing to our knowledge of galaxies, nebulae, stellar evolution, extraterrestrial life, pulsars, quasars, the outer planets, supernovae, binary stars, the analysis of starlight, the surfaces of other worlds, how a telescope works, what an astronomer does, or a thousand other astronomical concepts and topics. It cannot show us the proper motion of stars or take us on a journey to another part of the galaxy. As Henry C. King puts it, in *Geared to the Stars*:

"The Zeiss sky, unsupported by other visual elements, puts the lecturer in the position of someone who, confronted by a fish-bowl, is

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expected to describe the contents and extent of the ocean."

In order to overcome some of these limitations, planetarium staff members have designed and built an amazing array of supplementary projectors. Technicians have become optical and mechanical wizards who can fashion highly realistic projections of rotating galaxies, zooming spacecraft, tumbling asteroids, and evolving stars. They often have to be fiscal wizards as well, for their inventions and devices must be put together on a budget that wouldn't pay for three seconds of a theatrical film or a television program. Some of the most imaginative design engineering known to man has taken place in the workshops of North American planetariums.

Equally ingenious has been the development of systems to provide a circular landscape around the base of the dome. In the early years, some planetariums mutilated their domes by cutting out a silhouette of buildings or hills. In one or two cases, scale model buildings and other features of a landscape were mounted on hydraulically-lifted rings so a particular setting could be raised into place or lowered out of the way at will.

But in most planetariums today, landscapes are shown by optical projection. Up to fourteen projectors, spaced equally around the perimeter of the dome and operating in unison, may be used to create the illusion of a single, 360-degree landscape of another planet, a city, or the surface of the Sun. In some instances, artwork is used; in others, photographs are taken in the midst of a landscape or table model. Either way, breathtaking precision is required in both photography and projection. Over a distance of up to seventy feet, a minor discrepancy in the placement of the slide or the projector can move mountains.

Serious limitations remain, however, to what can be done conveniently in a planetarium through the use of slide projection and special effects. Some of these limitations were brought clearly into focus when comparisons were made between *2001: A Space Odyssey* and planetarium shows. Subsequent films such as *Star Wars*, *Close Encounters of the Third Kind*, and *Star Trek* merely confirmed these unfavorable comparisons. Let's take a simple example and look at it from both the planetarium's and the motion picture's point of view.

The problem: Show a spacecraft traveling toward a distant planet. Here are the solutions as offered by

the planetarium and the motion picture production company.

A planetarium would likely project a well-vignetted slide of the object, have it appear on one side of the dome, and, by means of bouncing the image off a slowly-moving mirror, arrange to have it travel toward the other side. A zoom lens could be used to make the spacecraft get smaller as it goes, suggesting that it is moving farther away. All this time, the projection planetarium is displaying the starfield of the Earth around it — and, unfortunately, through it. Even if the spacecraft is supposed to be on its way to another star, the familiar earth-night constellation will remain in view. And, of course, the stars cannot be shut off as the spacecraft appears to move in front of them. So they remain, suggesting to the unwary audience that they now have the ability to see with X-ray vision!

None of this is a problem for the motion picture producer. Through the use of animation he can adjust the starry background to show the changes along the interstellar course. He will use a model spaceship, and it will be filmed as it passes in front of

Planetariums continue to maintain a maddening aloofness from one another and from their mutual problems.

the starry background, so the stars will blink out and reappear as it goes. It's more costly and it involves highly skilled technicians and designers, but the end result is a more realistic portrayal of space travel. And it's just one of many instances where planetarium technology hasn't kept up.

2001 created another trend that had significant effects on planetariums. In the last twenty minutes of the movie, the astronaut is swept through a staggering series of abstract and psychedelic images. From that sequence we can date the genesis of the planetarium laser-light show, an art form that came to life in Los Angeles in 1973 in the talented mind and hands of Ivan Dryer. The laser was the perfect source for the brilliant light and mottled images that turned on audiences in 2001. Dryer formed a company, Laser Images Incorporated, and produced a show called *Laserium* which has since played to packed houses throughout North America, Europe, and Japan. Ironically, it has found its home in planetariums, particularly in those which found attendances dropping

as interest in space exploration dwindled in the early 1970s. Now the laser-light show is a permanent fixture in many shows.

Another development which had major impact on the future of planetariums took place in Canada in the early 1970s while a group of filmmakers experimented with a new way of using 70mm film. Advanced techniques in cinematography and a unique method of film projection made the new system, IMAX, the most stunning development yet. The IMAX picture was larger, brighter, and more distinct than any other.

The first IMAX film was shown in 1971 at the Cinesphere theater in Toronto. It caused a sensation then, and it continues to impress audiences to this day. You see an IMAX film in action when you attend the show on the lower floor of the National Air and Space Museum in Washington, D.C.

In a subsequent development, the IMAX Corporation — headquartered in Cambridge, Ontario — created OMNIMAX, a process by which films could be projected across the dome or curved screen of a planetarium. The first theater to exhibit OMNIMAX was the Reuben Fleet Space Theater in San Diego, which opened in 1973. Other similar installations have gone into operation in Seattle, Washington; St. Paul, Minnesota; Monterrey, Mexico; and a number of other cities. OMNIMAX shares the films they produce so high production costs can be defrayed, and has been largely responsible for bringing the advantages of film to the planetarium.

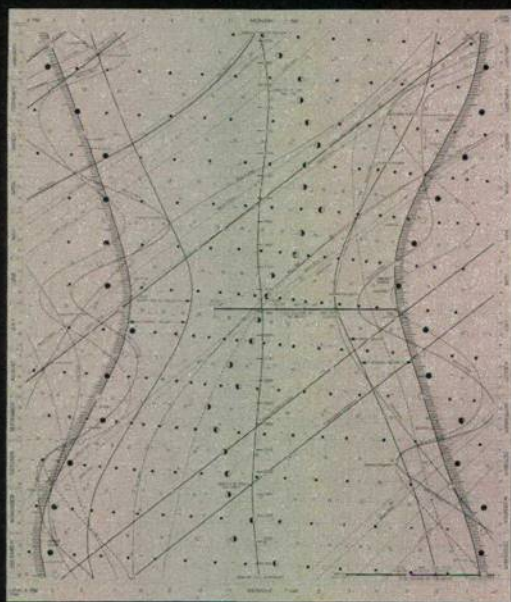
As they struggle to survive the impact of laser-light shows and wide-angle motion pictures dealing with astronomy, you might think that traditional planetariums would combine their resources and concentrate on what they do best. Instead, they continue to maintain a maddening aloofness from one another and from their mutual problems.

If the people responsible for planetariums don't take steps to standardize their equipment, their designs, and their policies, then others will force it on them.

Without cooperation, the exchange of shows among major planetariums remains virtually impossible. Scripts and soundtracks are exchanged on occasion — although there is no guarantee that the sound reproduction systems in any two planetariums will be alike — but even then, geographical references in the script may make a change of locale difficult. "And as

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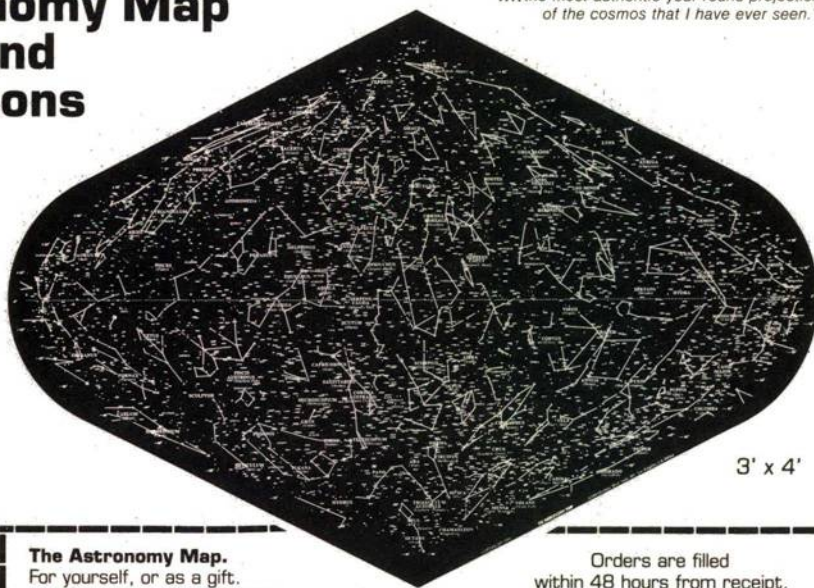
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we watch the Sun set over the Golden Gate Bridge . . ." might make sense in San Francisco, but it wouldn't go over well against a Miami panorama.

Sound systems differ, too, and automation systems vary. Even production philosophy changes from planetarium to planetarium. One program might tell you to be extremely cautious and scientific in your approach to reports of UFO sightings. Another might tell you that all sightings are manifestations of alien spacecraft in our midst.

To compound the injury that renegade independence does to planetariums, no other field seems to have such a pronounced tendency to re-invent the wheel. In 1970, Dennis Gallagher, then director of the Manitoba Planetarium in Winnipeg, decided to set up a company to produce traveling planetarium shows. Knowing the lack of compatibility that existed, he planned to bring all his own equipment — as a circus would — to every planetarium that engaged the services of his company. There was resistance to Gallagher's proposal, but it aroused sufficient interest and curiosity to bring well over a hundred planetarium directors and staff to the world premiere of his first production — *The Beginning and End of the World* — in Winnipeg, in September 1971.

Backed by over \$100,000 in loans and grants from the government of Manitoba, the company, Omnitheatre, Ltd., attracted a group of very talented and creative technical people to produce its first show. Gallagher even had an original score composed by Victor Davies and performed by the Winnipeg Symphony Orchestra under the baton of Skitch Henderson. He also signed Vincent Price to record the narration.

But when it came time for the black-tie premiere of *The Beginning and End of the World*, the show didn't go on. Over 200 guests and dignitaries sat in the dark, listening to the soundtrack. Why? Because Gallagher and his staff decided to ignore most of the current achievements in planetarium technology and start all over. They even invented their own computer to operate the show — and it didn't work. Although it eventually performed at a subsequent engagement in Denver in 1972, the damage had been done. Within a year, Omnitheatre, Ltd. had folded, and the idea of a syndicated, traveling planetarium show was set back at least a decade.

When we look at the demise of the "planetarium of the future" as

well as that of the past, we should try to understand why people build planetariums. Many were built because individuals were touched by experiences they had while visiting planetariums. Curiously, most of these experiences took place when the planetarium was in its infancy — when Herr Professor was still battling "The Wonder of Jena."

When they harbor the best intentions, planetarium benefactors hope that their fellow citizens can have the same wonderful experience they had. When they have less than ideal intentions, perhaps they are trying to achieve a kind of immortality via the celestial sphere. The planetariums of today are not unlike the great cathedrals or pyramids of the past. One astronomer referred to the creation of this type of monument as "writing graffiti on the walls of history!"

Capital donations for planetariums fall upon unwitting cities or universities which are then forced to accept the burgeoning operating costs in perpetuity. Some observers of this phenomenon suggest that the situation ought to be reversed, and the city or college put up the capital

The planetarium creates a feeling, a mood, an inspiration that makes it more akin to a temple than to any theater or classroom.

funds if some wealthy benefactor will pay for or endow the operating costs!

And what do cities or colleges know about running planetariums? No more than most of them know about running aquariums or museums. They have a vague idea that they must have some educational value and that perhaps audiences will be thrilled by an imaginary trip to the Moon. What they seldom realize, until it is too late, is just how limited the planetarium really is. Its ability to deal with university-level astronomy can be dispensed with in the first few lectures of a semester — after the stars have been identified, the coordinate system explained, and some time has been spent on retrograde motion and precession of the equinoxes. Disillusionment sets in rather soon.

However, in spite of wide-angle films and other visual delights and diversions, the planetarium still has one field all to itself, and when it fully exploits it, it has no equal. That, of course, is its ability to show the starry sky and to place an audience in the middle of an environment. It's

only when imaginative planetarium programmers concentrate on these strengths that they kindle the emotions that prompted the Haydens, the MacMillians and the Strassenburghs to part with some of their millions. With a background of soft music, the stars gliding past, and an occasional satellite or meteor writing its signature across the celestial sphere, the planetarium creates a feeling, a mood, an inspiration that makes it more akin to a temple than to any theater or classroom.

But planetariums almost seem to apologize for showing the stars or creating a mood — as if this denoted a failure to find a blinding special effect or a graphic slide or a burst of recorded cacophony to fill each second of a program. The problem is that the Hollywood motion picture has revolutionized astronomical special effects and people can look at slides at home or in a lecture hall. The farther the planetarium drifts from creating natural environments in its circular theater — either by staging laser-light shows or by trying to compete with movies — the more irrelevant it will become.

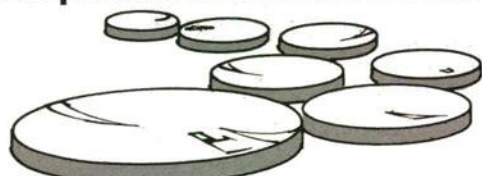
The planetarium as we know it can survive only if it remains true to itself. It is no longer the only way to communicate astronomy, nor is it the most efficient. A motion picture or television series may cost a fortune to produce, but once the show is on celluloid or videotape, it can be seen in every theater or shown over every television station in the world. A planetarium show can be produced for less, but it will be seen in one location by only a few thousand people — at best.

The planetarium can be a wonderful community information and resource center, and many succeed in this area today. The planetarium can also be a theater of the mind. The planetarium of the future, that I see, will take an audience to the surface of Mars or Titan, recreate the atmospheric effects that would be seen there, and demonstrate a sense of being on an alien world. Or, it will place them in ancient Greece or Rome, in Herschel's London or Lowell's Flagstaff, so that they might explore the heavens and contemplate their meaning for Man.

In a very few years we will all know whether the planetarium can go on developing or whether, like the dinosaurs, it will have served its period of usefulness on this planet and can look forward to a sudden and somewhat unlamented extinction.

David A. Rodger
Vancouver, British Columbia

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eye on the sky

venus reaches greatest brilliancy

by Fred Schaaf

the wanderers

The most interesting planet to watch during December is the Evening Star, **Venus**. This month, it reaches greatest brilliancy and begins the swift motions and phase changes that accompany its approach to Earth and its dramatic exit from the evening sky.

Even experienced observers marvel each time Venus reaches its maximum magnitude. At these times it can cast a shadow in a dark setting and even become visible to the naked eye in broad daylight. By day, Venus is a steely glittering point, and by night it is a powerful lantern, visible even through moderate cloud cover.

Greatest brilliancy occurs on December 16, when Venus attains a magnitude, of -4.4 — a rare occurrence. The planet will even outshine first magnitude Aldebaran by as much as Aldebaran outshines the fainter stars visible in country skies.

Time-honored formulae for **A Perseid fireball (below)** photographed by J.R. Westlake with a 16mm f/3.5 lens. Above right: the third quarter Moon through an 8-inch scope on ASA 400. Photo by Michael Haigh. The setting Sun (below right) through a 2000mm lens on Kodachrome-25. Photo by Brian Longbotham.

measuring brilliancy are adequate for most observers, but newer formulae show that Venus is brighter at greatest brilliancy than has been generally supposed. The difference from the old predictions is at least 0.18 magnitude at any greatest brilliancy — though it can barely be distinguished even by an experienced observer. Using this correction factor, we find that Venus at this month's greatest brilliancy actually shines at an awesome -4.56.

Venus' prominence makes it an excellent "Christmas star." It attains its greatest sunset elevation in the middle of the month when it passes very close to 6.0 magnitude 4 Capricorni. For the first half of the month, Venus sets three full hours after the Sun, but then begins a rapidly accelerating descent as the planet approaches us and our line of sight to the Sun. On the last evenings of 1981, Venus sets 2½ hours after sundown and is just a few weeks away from leaving the evening sky. Its crescent will become so large and skinny that it can even be glimpsed in steadily mounted binoculars.

Moving over to the morning sky, we see three of the classic planets — each of them brightening. **Mars** starts rising before midnight around Christmas and is high in the south in late

December as morning twilight begins. The planet then leaves Leo for Virgo and brightens rapidly, surpassing Spica at first, and then rivaling Saturn. The gap between Mars and the Saturn-Spica duo dwindles dramatically, while on the eastern end of Virgo, the brightest morning planet — **Jupiter** — shines at about -1.4 magnitude for late night observers.

Early in the month, a long and beautiful parade of bright objects — **Regulus, Mars, Saturn, Spica, and Jupiter** — extends eastward across the morning sky at regular intervals and in increasing order of brightness.

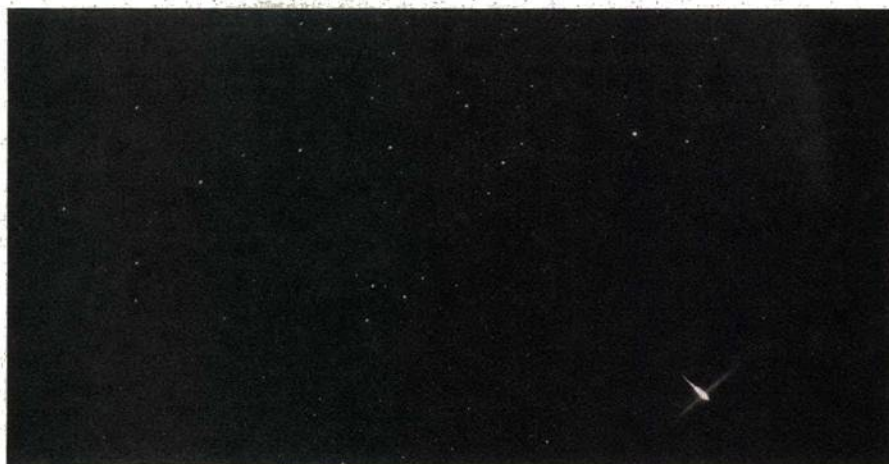
Mercury spends all of December in obscurity, and reaches superior conjunction and aphelion on the 10th, when it will attain its greatest distance from Earth this decade.

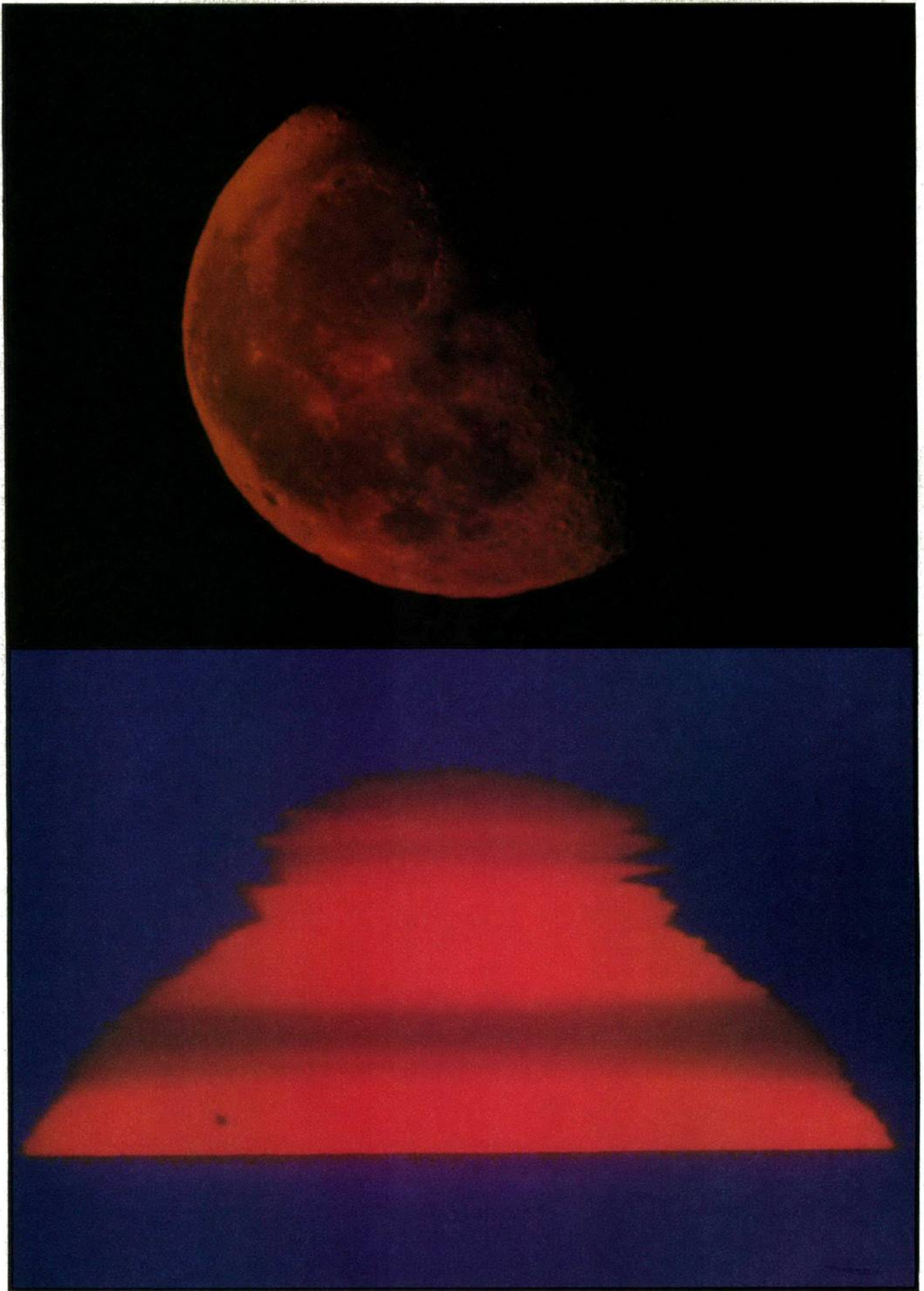
The **Moon** is a few degrees north of Mars on the morning of the 18th. It lies between Jupiter and Saturn on the morning of the 20th, and then returns to the evening sky on the 28th — 2° south of Venus.

the starry sky

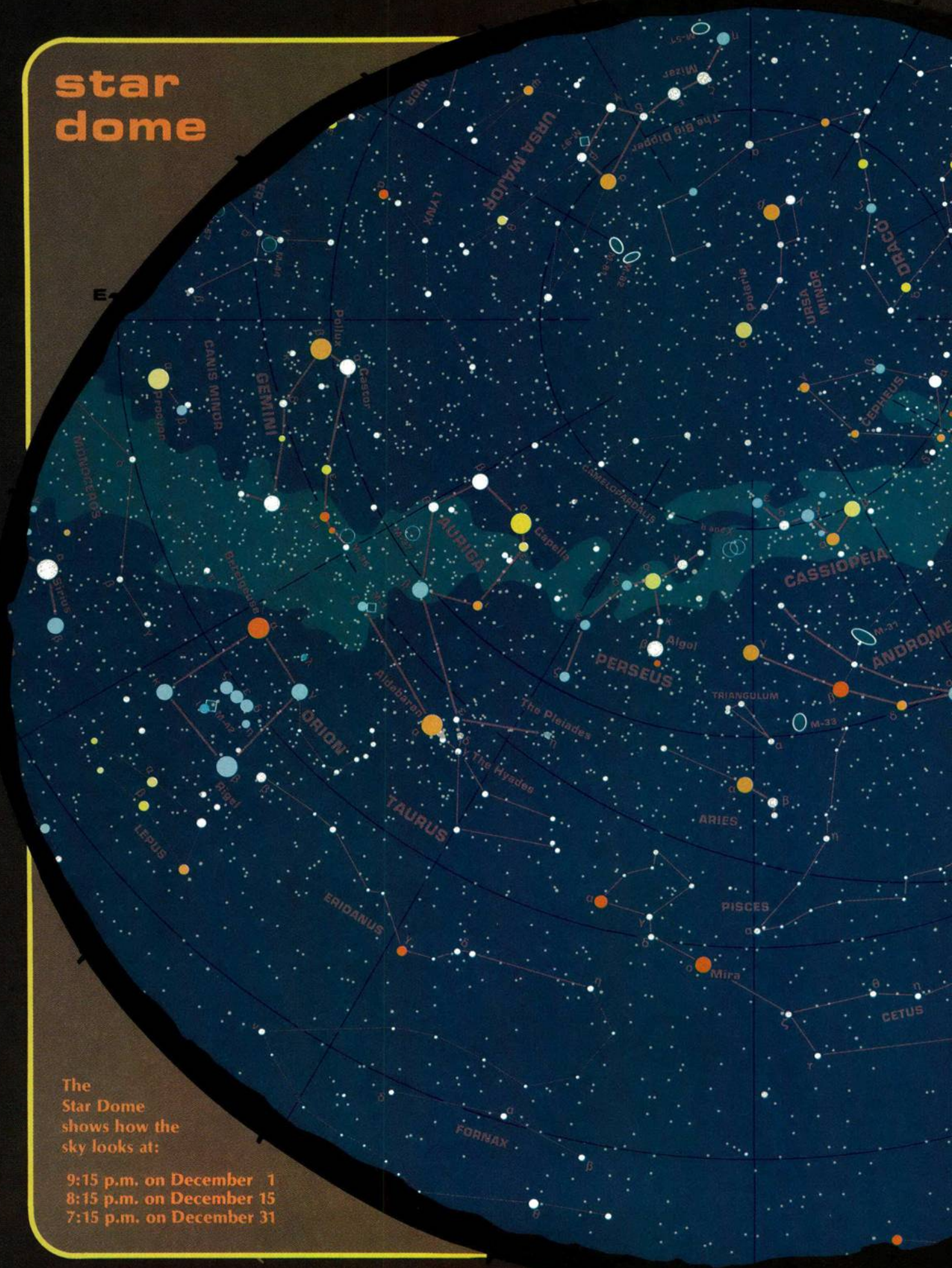
Winter's long nights present our last views of the Summer Triangle in early evening, and its mornings display the planet-bedecked length of Virgo. Between these two extremes lie many hours of excellent observing among the autumn and winter constellations.

At 10 p.m. **Pegasus** descends the western slope of the heavens, with **Andromeda** trailing behind. The brightest stars of Andromeda are (west to east) Alpheratz, Mirach and Almach — all nearly equal in magnitude. Just beside the second faint star north of Mirach is the **Great Andromeda Galaxy, M-31**. We have no record of this mysterious 4th magnitude patch of radiance from ancient times, but its absence probably stems from a lack of surviving documents. We do know that M-31 was observed by Arabian astronomers more than 600 years





star dome



The
Star Dome
shows how the
sky looks at:

9:15 p.m. on December 1
8:15 p.m. on December 15
7:15 p.m. on December 31

december sky almanac



- 4th** First Quarter Moon is at 11:22 a.m. EST.
- 10th** Mercury reaches aphelion (farthest from Sun) and superior conjunction. The Moon is at perigee this evening: 221,711 miles from Earth.
- 11th** Full Moon occurs at 3:41 a.m. EST
- 13th** Peak activity for the Geminid meteors begins late tonight and will continue into the early morning of the 14th. Expect the nearly Full Moon to interfere.
- 15th** Jupiter now rises around 4 a.m. local time. Look to the southeast in the predawn hours. Saturn is there, too — higher, but dimmer, in the south-southeast. Mars — almost as bright as Saturn but orange — appears in Virgo and crosses the meridian shortly before sunrise.
- 16th** Venus is at greatest brilliancy in the evening sky tonight, -4.4 magnitude. Also, Neptune is in conjunction with the Sun.
- 18th** The Moon is at Last Quarter at 00:47 a.m. EST, and lies near Mars in the morning sky.
- 21st** Winter commences at 5:51 p.m. EST — the solstice.
- 22nd** The Ursid meteor shower will peak early this morning. Look near the Little Dipper for about one bright meteor every five minutes.
- 23rd** The Moon will be at apogee this evening: 252,510 miles from Earth.
- 26th** New Moon is at 5:10 a.m. EST.

● 1st magnitude and brighter

● 2nd magnitude

● 3rd magnitude

● 4th magnitude

○ clusters ◇ nebulae ○ galaxies



before Galileo scanned the skies.

M-31 is the most distant object visible to the naked eye — about 2.2 million light-years away. If you have very dark skies, look the same distance southeast of Mirach as M-31 is northwest. There, not far from the apex of Triangulum, you may spot **M-33**, another splendid galaxy that lies 2.4 million light-years away. The naked-eye visibility of M-33 is a good test of atmospheric transparency as well as dark adaption. This 1° wide galaxy is often more prominent in binoculars than in a telescope, because it has such a low surface brightness.

North of Andromeda is the mythological maiden's mother, **Cassiopeia**, a fine "M" of stars sitting atop the north circumpolar group on December evenings.

Next door to Cassiopeia, bright **Perseus** contains striking star clusters visible to the naked eye. Most famous are the side-by-side glows of the **Double Cluster** — just above the helmet of the hero's figure. They were known in ancient times and given the designations of η and χ (Chi) Persei by Bayer. Their integrated magnitudes are 4.4 and 4.7, respectively, and make them easy naked-eye objects in a dark sky. These clusters are famous showpieces for telescopic viewers, but also deserve plenty of binocular and unaided eye observation. The naked-eye appearance of the Double Cluster is enhanced by dark skies and clear nights — yet, like the Beehive in Cancer, it can tantalize us with wonders just beyond the powers of vision.

Following Perseus up in the northeast is **Auriga** the charioteer with the very bright star Capella and three 2nd magnitude stars nearby called the **Kids**. The pentagon of Auriga encloses several fine clusters for binoculars, and is hooked at its southeast corner to a horn of **Taurus** the bull. Farther south is Taurus' prominent face, outlined by the **Hyades** cluster which forms a "V" or a triangle with the bright star Aldebaran. Above the Hyades is the richer and even prettier cluster, the **Pleiades**. Most observers can count six or seven Pleiads at a casual look in dark skies — how many can you find?

The southern sky is mostly a vast, dim realm, speckled here and there with strands of faint stars. To the southeast of the head of **Cetus** the whale lies a meandering and dim constellation, **Eridanus** the river. Constellations like this are for true

The August 25 conjunction of Venus, Jupiter and Saturn revealed how the planets looked from Earth as Voyager 2 headed for closest approach. Paul Roques, of Newhall, California, made this 30-second exposure through a 135mm lens on Ektachrome 400. An experimental filter produced the star-like spikes.



Above: The Venus of Willendorf, a fertility statue dated 15,000-10,000 B.C. and found near Willendorf, Austria. Right: A detail from Botticelli's *The Birth of Venus*, 1484-1488.



connoisseurs of the sky, since they are dim and difficult to locate. Remember that this north-south river has bright and interesting endpoints. On the southern end is first magnitude Achernar, always far below the horizon for North American viewers. At the northern end is a moderately bright star, Cursa, located just a few degrees from some of the most splendid configurations in the sky — Orion the hunter and his host of winter constellations.

skylore

The ancient lore concerning the dazzling planet we call Venus is plentiful enough to fill a large volume. But most of us do not realize that this gem has played important roles in the writings of many great 19th and 20th century poets.

A reference to a daylight — or at least bright twilight — observation of Venus appears in one popular poem, but only an astronomically minded reader would pick it up. In Shelley's "To a Skylark," the speaker likens the clarity and presence of the bird's song to that of the light of Venus:

Keen as are the arrows
Of that silver sphere,
Whose intense lamp narrows
In the white dawn clear
Until we hardly see — we feel that it is there.

This is an excellent description of how Venus looks as a Morning Star near sunrise.

Probably the most significant use of Venus by a poet of this period occurs in a work of Alfred, Lord Tennyson. In that star-loving poet's "Crossing the Bar," he begins with what is one of the most powerful and poignant phrases ever written:

"Sunset and evening star,
And one clear call for me!"

Twentieth century poets have also alluded to Venus in their work. This poem, written by Austrian poet Rainer Maria Rilke and translated by Eleanor Berry, literally tracks the movements and appearance of Venus in its passage across the sky.

Strong star, which does not need the help
the night must give to the others —
first darkening so that they grow bright;
star which, already consummated, disappears

when constellations begin their courses
through the slowly deepening night;
great star of Love's priestesses,
which, on fire with its own feeling,

ablaze to the last, never consumed,
sinks down, there where the sun sank,
surpassing thousandfold ascension
with the pure descent.

ASTRONOMY IN FOCUS

Cosmos Controversy

Sir / Regarding the letters in past issues of ASTRONOMY that labeled *Cosmos* and Carl Sagan's approach to science as basic and simple-minded:

While the show did have a very basic approach, I don't think this was a mistake. Sagan was primarily interested in the general public, whose scientific knowledge is very basic; for these people, *Cosmos* was not an education, but an introduction.

This approach worked. For the first time in my ten years of schooling, I saw science enjoying a mild popularity. Teachers videotaped episodes and played them for their classes. In other words, the show was accepted and was used to pass along an interest in science.

Those who found *Cosmos* too basic should ask themselves which they prize more highly: an hour of entertainment, or the acceptance of science by the public.

Mark Pollack
Bloomfield, NJ

Cosmos Controversy, Cont'd

Sir / I was very angry after reading the letter sent in by Kenneth Kalish (ASTRONOMY, July 1981) concerning the *Cosmos* series. If Kalish is so far advanced that he can't "bear" a series made for the average viewer, then maybe he ought to throw away his television.

Kalish's slanders against Sagan were less science-minded than Sagan's series. And in judging *Cosmos* for scientific facts, putting down Sagan's personality is a little off the track. After all, *Cosmos* managed to do what it set out to. It reached the average viewer and made him aware of the fascinations of the heavens.

I think Sagan did a good job. If he

had filled *Cosmos* with difficult scientific facts, the series would have been over the heads of most viewers. And if Kalish is so strongly convinced of Sagan's incompetence that he would cancel his subscription to ASTRONOMY over an article on *Cosmos*, then maybe he ought to publish his own magazine to insure perfection!

Sunchie Breipp
Lexington, MA

Space or Butter?

Sir / In a time when Congress passes, *without reading*, a budget that contains awesome cuts in social programs, our nation is faced with problems far more serious than the loss of the Halley mission. While cuts are made in social security, welfare, food stamps, and CETA programs, the Viking Fund asks us to feed a starving robot.

We learned patience with our stargazing, waiting for the skies to clear. We must be patient now, hoping for the economy to strengthen, and resist the temptation to fund a glamorous space project at the expense of a mundane jobs program.

As for the argument about the prestige of our space missions, we earned long ago the prestige that comes from great technical achievements. We will earn far greater prestige when we show that we are more interested in feeding people than in feeding robots.

Eric Carleen
Waltham, Maine

Unity for Space

Sir / The phenomenal success of the Voyager 1 and 2 missions proves that the United States is a world leader in space technology. But this is changing. There will be a lull in U.S.

planetary exploration while other space-faring nations eagerly pursue research on the solar system.

What can we expect from the rest of the world's exploration? Can the Soviet Union overstep the political boundaries set up by both of our governments and release detailed information? Can they recognize the entire world's need to know about our universe? Will the U.S. and U.S.S.R. ever recognize the need to unite scientifically?

I urge the United States, the Soviet Union, and the rest of the world to muster the courage and unity needed to take the next step for mankind — into the cosmos.

John McDonald
San Francisco, CA

Another Country Heard From

Sir / *Cosmos* is on its first showing in England, and has been highly praised. I've heard a number of discussions between the elderly and young alike. They say it is helpful, beautifully put together and amazingly easy to understand — especially when compared to other scientific programs in which some time-worn boffin tries to blind us with Science.

I thank Carl Sagan for reawakening the curiosity I had as a teenager about what was "up there." He has challenged me to learn more: a challenge I intend to accept. At the age of thirty-three, I plan to start further education courses next September.

I enjoyed the letters in your July edition, apart from one chap who, after criticizing *Cosmos*, admitted he watched *Charlie's Angels*. I found this quite amazing, but there's no accounting for taste!

I happen to like Dr. Sagan's smiling face, not to mention that smashing voice. And, after all, it was

a "personal voyage" and I felt privileged to be able to share it. As for him being sexy, well, he says, "The Cosmos is gorgeous"; I say, "He is not so bad himself."

Susan Seddon
Runcorn, Cheshire
England

Assemble or Build?

Sirs / I have heard it said that I could save a lot of money over the cost of a commercial telescope if I built it myself. That seemed good to me so I wrote off for all the catalogs from the manufacturers. Well, when I added up the prices for all the parts, with the focuser and a fiberglass tube, plus the spider, the mirror cell, a mirror and a diagonal, a right angle finder, and an equatorial mounting with a drive, I saw it costs more to do-it-yourself than to buy a finished telescope — or at least more than some brands. What gives? What's the secret?

Walt MacKenzie
Los Altos, CA

Mr. MacKenzie / There is quite a difference between building a telescope and buying the components to assemble one. Telescope builders make mirror cells from metal or plywood, telescope tubes from spiral wound paper, and mountings of all kinds from humble pipe fittings or precision-machined shafts. You can see truly homemade telescopes at the Riverside meeting in California, the Stellafane meeting in Vermont, at meetings of the Astronomical League, and at star parties held by local astronomy clubs. ASTRONOMY carried articles on two of these meetings in its September and November issues this year. In talking to the builders, you'll find that making your own telescope can be a deeply satisfying experience.

We recommend that you examine the design for a 10-inch Dobsonian telescope in our June, July, and August 1980 issues, as well as the series on making a 6" reflector in the April, May, August, and September 1977 issues of ASTRONOMY. You'll see that if you buy all the parts, they can cost several hundred dollars — but if you build, you pay only for the materials. TELESCOPE MAKING magazine also features unique telescope projects that can be built at relatively low cost.

Programming the Beginners

Sir / I have some comments in support of the letter titled "Observational Letdown" in the June 1981 issue.

I clearly recall my own confusion when, as a beginner, the first object I saw in a telescope was the great globular cluster, Omega Centauri. I couldn't understand what I was looking at. Now that I've had more observing experience, I use a step-by-step method to help beginners understand what they are seeing.

A typical program might run along the following lines:

Turn the scope to a single bright star — Sirius, for example.

"Oh, how bright it is," they say.

Then look at a contrasting colored star, say Betelgeuse.

"Wow, isn't it red!"

Then a cluster such as the Pleiades.

"Look at all those bright stars!"

Next, try the "Jewel Box" cluster in the Southern Cross.

"How beautifully colored!"

At this stage, I can show them Omega Centauri (sorry about that, northerners).

"Hey!"

I then show them the clouds of Magellan as an illustration of other galaxies (sorry again).

We end up with a bright object such as the Eta Carinae Nebula.

With each object in the eyepiece, I give my commentary from a "cue-card" which fits in my shirt pocket. The Whangarei Astronomical Society is making a set of these to help us on our public observing nights.

I have found this approach a great help for beginners.

Robert S. Adam
Whangarei, New Zealand

Ooops!

In the diagram on page 44 of the August issue, the telescope at top left is an achromatic refractor, not a reflector.

The Sun's surface gravity is 28 times greater than Earth's, not 300 times as stated on page 10 of the October issue.

The two outside photos on the bottom of page 75 in the October issue were transposed. Lower left is a 10-micron image of W3, an HII region in Cassiopeia. Lower right is the galactic center at 10 microns.

behind
the scenes

our 101st issue!

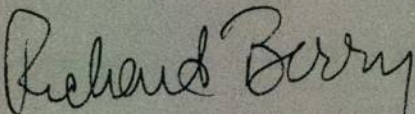
Just the other day, Bob Maas, the president of AstroMedia, asked me if I knew that the November ASTRONOMY was issue #100. Well, I had to admit that I hadn't even thought of it. Robert Burnham and I were working on the Saturn feature, and since that issue was the thickest ASTRONOMY ever produced (116 pages) and had the largest press run ever, I hadn't any time to think, let alone count up issues. Anyhow, I'd like to thank our charter subscribers for sticking with us for the last eight years, and welcome aboard our new subscribers. You have all helped make ASTRONOMY a success.

Beginning with this issue, we're making a change: our monthly telescope observing department, Through the Eyepiece, will now be called The Backyard Astronomer. We want to make 100% sure that our readers, especially our new readers, will understand who we write it for. Eye on the Sky — for naked-eye observers — and The Backyard Astronomer — for telescope observers — are the places in

ASTRONOMY where you find all the monthly observing information you need.

Now for an unusual request: please send us your worst astrophotos. We were planning an article on common problems in astrophotography, covering everything from bad guiding to out-of-focus stars to lens flare. But when we looked in the photo files, we couldn't find enough. We'd appreciate seeing your bloopers — the pictures that didn't work out — so that we can illustrate this upcoming article. In this way, you can help other astrophotographers avoid those same frustrating problems.

Sincerely,



Richard Berry
Editor

P.S. Please send them to:
"Bloopers"
c/o ASTRONOMY
P.O. Box 92788
Milwaukee, WI 53202

Orion for Christmas

Orion is the place for one-stop Christmas shopping. We're stocked up and ready to fill your order fast. Quick Delivery via United Parcel Service. Phone us now for up-to-the-minute stock and delivery information. Need help making a selection? Just call us today at (408) 476-8715. SHOP EARLY TO AVOID DISAPPOINTMENT!

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Giant 10x70 Binoculars

The wide 5° field of our fully-coated premium giant binocular is just as bright as 38% heavier T1x80 types. Much easier to hand-hold. Ideal deep-space binocular, best single-piece cast bodies, with case and straps. Certificate of Collimation and Orion's 2-year warranty. #9505—\$149. 'L'-type tripod adapter, #5250—\$5.95.

Polar Alignment System

Our micro-fine adjusters let you "tune in" your polar alignment with easy knob adjustments. Fast, simple alignment in minutes with our easy-to-follow directions. Nothing else needed. #5423—\$46. Altitude portion only (wedge tilt), #5421—\$19.95. Azimuth only (for those with our earlier wedge tilt model), #5422—\$29.95.



Dew Cap For C-8

Matching orange epoxy finish, extends viewing time. Light, easy to attach, black interior. #5180—\$34.95.

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Easy set-up and adjustment with our best quality knobs for wedge, tripod, and telescope fittings. Guaranteed unbreakable. 12 knobs. #5612—\$11.95.

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Large aperture straight-through or right-angle finders make faint objects easy to locate. Large selection. Call or write for pricing and models available.

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Adjustable-height swivel chair folds for storage, and lets you sit at the right height for no-strain viewing convenience. You'll wonder how you managed without it! #5935—\$47.

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Excellent quality Orthoscopic and Kellner eyepieces. Get the most out of your scope by having the right one when you need it. Selected types for best performance value, fully-coated, 1.25" barrel. 40mm, 25mm, 18mm Kellners—\$18. 12.5mm, 9mm, 7mm, 5mm Orthoscopic—\$26.

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The finest modern eyepieces available today. Superb mechanical and optical quality. 7.4mm, 10.4mm, 13mm, 17mm, 21mm, 26mm. \$55 each.

NEW!



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Our new Dew Zapper counteracts 'radiant cooling', the cause of dew formation. Runs on 12-volts DC or 117-volts AC. Control box with adjustable output, pilot light. Dew cap recommended for maximum efficiency. #3500—\$57 introductory price.

NEW!



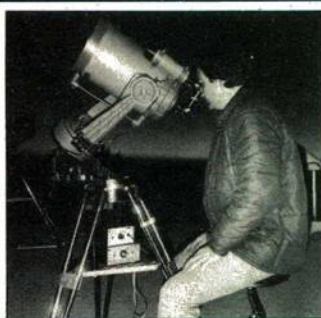
Tripod Lowering Device

Lowers C-5/8 tripod to comfortable height for sitting in a regular chair. Includes special extension bars and tensioner knobs. #5441—\$27.

Observer's Eye Patch

Lets you keep both eyes open, for relaxed viewing without stray light. Elastic strap. Perfect for pirates too. #5940—\$4.95.

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is that lens a star performer?

by
Frithjof Sterrenburg

photography
in
astronomy

One of the most crucial elements in simple astrophotography is often overlooked. While you take great pains to properly align your scope and attach the camera solidly to it, and while you try your darnedest to keep the guide star centered or not to trip over your tripod, you probably don't think about the quality of the camera lens you're using. But ignoring the quality of this main optical element is a grave mistake, because even if you overcome Murphy's Law, a bum lens will only give you the poor results you're trying to avoid.

There is no more instructive astronomy project than taking a 10-minute, carefully guided piggyback astrophotograph. Make a print of the negative and get out your best star atlas, then try to identify the hundreds or thousands of objects your astrophoto shows. It's hopeless — you won't be able to identify more than a fraction of the brighter stars. That simple picture you took with ordinary film and a regular 35mm camera shows far more stars than the best atlas you will ever possess.

Could You Do Better?

You might wonder whether a better lens would show even more. But what is a better lens and where can you find one? And what does "better" actually mean in this respect? Suppose you did not make any gross errors during the exposure — like not fixing the camera properly so that it slowly sags while you take the picture. If you carefully examine the corners of the print (or the negative, using a magnifier), you will notice that the star images are not perfectly round. Is that a shortcoming in the lens or an improper alignment of the polar axis?

These problems become even more confounding if you want to buy a new lens with piggybacking uppermost in your mind. The average camera salesman can't tell you much about a lens's performance for astrophoto-

graphy, and many salesmen start wondering about the advisability of medical help if you tell them you like to do piggyback astrophotography.

Photography journals publish test reports of lenses, but how do these findings apply to star pictures? What do lines per millimeter have to do with star images? Is a \$400 lens really four times better than a \$100 lens and is your \$50 lens just a piece of junk? Don't despair if you can't answer these questions — there is a way out!

The Imperfect Lens

The salesman who doubted your sanity will simply throw you out of the store if you tell him the 500mm, f/1.4 super-telelens he can let you have for \$5,000 has about a dozen optical errors, or *aberrations*.

And yet you are perfectly right. There is no error-free lens in existence. Even the best lenses (for telescopes, microscopes, cameras or whatever) have what are called residual aberrations. The only thing a lens designer can do is reduce them to an acceptable minimum — bearing in mind what the customer wants to do with that lens. Optical errors that are

lenses are designed for.

The crux of the matter is that the lens maker has to decide what trade-offs he can make to keep the price of his product from skyrocketing. The only way to do this is by compromising. An objectionable error for one particular application can be controlled by allowing a bit more of a different error that is less objectionable for the intended purpose.

So let's look at some lens aberrations and see how your requirements for making good astrophotographs differ from what Uncle Hezekiah needs for his family portraits.

The Blue-light Problem

To illustrate one argument before it becomes complicated, suppose a customer is interested in images taken with only the light of a single wavelength (though this may seem unlikely, there are such applications). Obviously he will not worry about the chromatic aberration — the fact that light rays of different colors never focus in the same plane after passing through a lens. It is fairly easy — and not too expensive — to make the image for light of two colors coincide

chromatic aberration



perfectly acceptable for one application may be unacceptable for another. This is precisely what causes a problem for astrophotographers: your application of the lens is entirely different from what normal camera

with each other. However, if you want the lens corrected for three wavelengths, instead of two, then the price quadruples. Such lenses are called *apochromatic*.

Here is the first problem. The color

test photos

made with a variety
of lenses

edge of frame
50mm f/1.4 lens
at f/1.4

DIVERSEN
claims etc.

center of frame
50mm f/1.4 lens
at f/1.4

beleggingsfondsen

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eurint 1	68.50	
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50mm f/1.4 lens
at f/1.4

average
10.00

DIVERSEN
claims etc.

50mm f/2 lens
at f/2

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claims etc.

200mm f/3.5
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DIVERSEN
claims etc.

50mm f/1.4 lens
w/ expensive
3x teleconverter

50mm f/1.4
w/ expensive
3x teleconverter

These are highly
magnified portions
of test pictures of
fine newspaper
print. Compare the
quality that dif-
ferent lenses
produce.

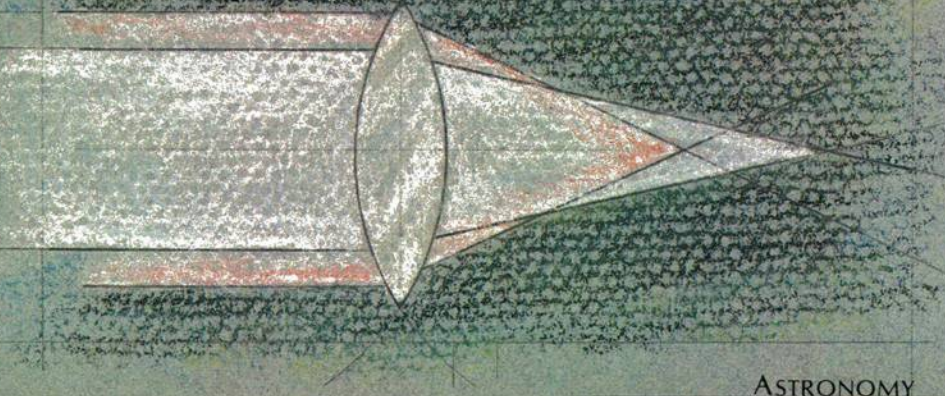
correction of modern lenses is amazingly good even if the lens is inexpensive. However, for ordinary photography the blue and violet wavelengths are not so important, so in making their trade-offs, the designers usually let chromatic aberration increase there. Toward the ultraviolet it becomes even worse. Unfortunately, starlight, like sunlight, contains quite a bit of blue, violet, and ultraviolet light. In addition, modern films are very sensitive to these shorter wavelengths, so that the lens and the film greedily gobble up short-wave radiation and you end up with bloated, blue, and imperfect stellar images. If grass and plants were violet, optical designers would surely correct lenses for that range of the spectrum. An ultraviolet

(UV) filter reduces the resultant fuzziness of the image, but also absorbs a substantial portion of the incoming star light before it reaches the film. This makes the image

dimmer.

However, chromatic aberration is usually not the biggest worry to the astrophotographer, since most modern lenses are well corrected for

spherical aberration



it. There are more insidious errors that make your stars look like seagulls, and will cause you to curse your wretched mount. This problem is called *spherical aberration*. Light rays coming through the center of a lens form an image in a different plane than the rays going through the edges. Spherical aberration is so detrimental to image quality that optical designers put it on top of their "hit list." Today, normal camera lenses are well-corrected for it, unless it's a very inexpensive lens.

Two Crucial Differences

There are two fundamental points in which piggybacking differs from normal photography. Let's go back to Uncle Hezekiah's fine collection of family snapshots for a moment. First, he's the fellow camera companies build cameras for. Second, he's only interested in the central object and not at all in the edges of the picture. People who take ordinary pictures will, as a rule, put the main point of interest more or less central in the frame. The lens designer sacrifices a bit of sharpness (resolving power) at the periphery to keep other errors in check, and most photographers don't object because they don't notice the error.

Of course, the performance of any lens deteriorates toward the edges —

much of an ordinary lens when you use it for astro-work. You will want to use it wide open and yet still need excellent definition at the edge of the picture. And finally, your photograph will consist of only high-contrast point-sources of light — one of the most critical tests for any lens.

Aberrations — When Tolerable?

There are at least a dozen aberrations besides the ones we have already mentioned, but we will restrict ourselves to an additional four that are common. All of these errors are related to the aperture (or *f*/stop setting), and especially to the law that errors increase toward the periphery.

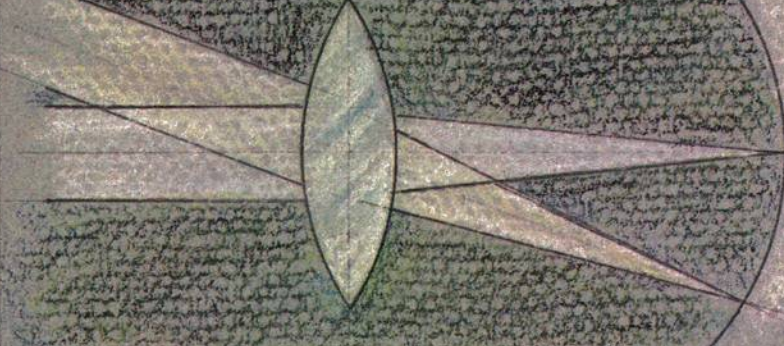
Curvature of field makes the image out of focus and therefore fuzzy at the periphery if you sharply focus the center — and vice versa.

Astigmatism means that small circles — your star images, in other words — become ellipses or lines.

Coma means that small circles become comet shaped.

Distortion comes in two varieties: barrel and pincushion — and causes straight lines to become curved. It is particularly noticeable in wide-angle lenses. For astrophotography where you intend to measure the star positions to the nearest $1/1000$ th of a millimeter, distortion is impermissible.

curvature of field



it's unavoidable. But in astrophotography, the loss of resolving power at the edges is much more objectionable than in normal photography. In normal photography some bit of background isn't sharp. In astrophotography, the stars look like seagulls or broken eggs or what-have-you.

Another phenomenon in ordinary photography is that the great majority of pictures are taken at middle range *f*/stops like *f*/5.6 or *f*/8, but in astrophotography you use the lens wide open. Inherent to all lenses is the fact that aberrations decrease when the lens is stopped down. Even the best *f*/1.8 lens will produce sharper images when stopped down to 2.8, and at settings of *f*/16 or so the differences between an expensive and a simple lens become very small.

It's obvious that you're asking too

astigmatism

round image

astigmatic image

development, small guiding errors and scattering of the light in the emulsion during long exposures are some of the factors that spoil the image quality. In other words, a lens can have aberrations that can be demonstrated and measured, but are not noticeable on the film.

How to Test

The best way to test a camera lens for astrophotography is to make actual piggyback photographs with it. Pictures of the same area of the sky, taken under absolutely identical conditions (film, exposure, light pollution, Moon phase, development) and with perfect guiding, will permit objective comparisons between various lenses. Apart from the obvious problems of maintaining identical conditions, this becomes a very time-consuming affair. But the biggest problem is this: How do you test 10 different lenses to find the one most suited to your needs? You can't buy them all and return the nine you don't want; and borrowing is definitely out of the question. What you're looking for is a test method that permits an objective comparison with a minimum of bother. You don't need scientifically exact results, but you must be able to test the lens without having to wait for a dark clear night — and preferably on the salesman's premises!

Take pictures of a standard test-object, so that its image completely fills the frame, and make your exposures with the lens wide open.

Always use the same film, a type with extremely high resolving power, and a fine-grain developer — and develop each roll identically.

As for the test object, manufacturers offer test-charts excellent for this purpose. However, two pages of a newspaper with very fine print also give useful results. The photographs shown were taken using the financial pages of a Dutch daily. The smallest print is about 0.5mm actual size, and the two pages are about 800mm actual size and reduced to fill the 24x36mm negative — a factor of 22. The smallest print will be about 0.02mm on the negative. If a letter or number is recognizable at this size, then the combined resolving power of lens and film has to be better than 100 lines per mm. Film of 25 ASA can resolve such

coma

round image

comatic image

minute detail and, since astrophotographs will be taken using films with much coarser grain, the test is very severe.

Practical Set-up

Suppose you want to test several lenses against one you already have. Most camera salesmen will allow you to take some shots through the lens you're interested in — if not, his competitor will! But make it easy on him and don't ask him to cater to your odd needs when the shop is crammed with people. Making an appointment during the slower hours is a good idea.

Once you're ready to get on with the test, place the camera on a solid tripod with the test object right in front of the camera. Make sure that the camera is at the same height as the center of the test object and is perfectly perpendicular to it, so the film plane and test object are parallel. The same applies sideways: the lens must be in line with the middle of the test object.

The camera-to-object distance is always best when the object just fills the frame — as checked in the finder. That will be about 1.5 meters for a standard 50mm lens, and about 6 meters for a 200mm telephoto lens. The size of the newspaper print on the film will always be the same — regardless of the objective's focal length — so direct comparison becomes easy. Focus with extreme care.

Make the exposure with the lens wide open so that you have to make the light-meter reading correct by selecting a proper shutter speed. It may be too dark inside a store. In that case you'll have to use a spotlight or take the test object outside. You cannot use a flash because you would have to stop the lens down to get the correct exposure. After this, all that remains is to examine your test shots at home.

How to Evaluate

The best way to evaluate the results is to examine the finished negatives directly under a microscope at 25 to 50 power — no more. The optics of a good microscope are so superb that minute details such as the film grain are still crisp. If you cannot use a

microscope to get an idea of the contrast in the image, examine the negative with a magnifier.

An alternative to studying the negative is to make prints. Although copying inherently brings losses, and the quality of the enlarger lens adds other variables, the results are fairly good if the enlarger objective is stopped down to $f/5.6$ or $f/8$. You'll have to enlarge enormously, and project on a wall. The resulting image will be so large that you'll have to make prints of only relevant portions of the negative. Always center the portion of interest in the negative on the printing board and use a hard grade of paper — the negative contains only black and white, no greys.

Since a printed page contains many straight lines — the margins of the columns, for example — distortion can be seen immediately. You can assess resolving power and most importantly you can see what the corners of the image look like. And you can always go back to your original, the newspaper pages, for a direct comparison.

Warning: You may be horrified. The center of the image is always sharp

1.8 is still good enough for piggybacking. Contrast increases tremendously, but this is much more evident on the negative.

What you may expect from a normal good camera lens is shown in the next picture, taken with a 50mm $f/2.0$ lens, wide open.

An excellent 200mm $f/3.5$ telephoto produced the next picture — at four times the distance of the others.

And now the horror cabinet: a comparison test of the superior 50mm $f/1.4$ used in the first two photographs and a cheap 3x teleconverter — both printed the same corner of the negative. OOPS!

The next is taken under the same conditions, but with an expensive 3x teleconverter. Its results are passable for snapshots, but a 135mm telephoto would be better.

To wrap it up, here are some morals based on a large number of tests:

— In general, expensive lenses are better than cheaper lenses (which is what you would expect) but not always so (which is why we test).

— Very fast lenses may become really good only when stopped down a bit.

distortion

no distortion

barrel

pincushion

when the lens is used wide open, but the corners can be awful. Although you cannot assess aberrations individually, the combined deterioration due to astigmatism, coma, and curvature of field may shatter your peace of mind. You've never seen such ghastly things in your normal pictures — because you have never scrutinized the negatives this closely.

Some Examples

On page 44 are some results that will help you evaluate your test.

The first is from an excellent 50mm objective used at its full aperture of 1.4. It is a portion of the negative at the extreme corner. The next picture shows newspaper print of the same size, but about a third from the center. There is definitely some loss of image quality toward the edges, but performance is superb.

To illustrate what consequences "wide open" use has, the next picture shows the performance of the same lens, again at the extreme corner, stopped down to 1.8. Just one stop makes a very marked difference and

— Zoom lenses are never as good for our purposes as lenses of fixed focal length are. Of course, they are much more convenient for ordinary photography than a battery of lenses.

— At $f/5.6$ the differences become very small, and at $f/8$ all negatives start to look the same.

Where does all this leave the would-be lens purchaser? In short, buy a quality lens — well constructed both mechanically and optically — because some bargain lenses can leave your stellar images looking like seagulls. On the other hand, you don't need an expensive lens to do piggyback astrophotography. Finally, consider more than the price. Choose the lens that has the best image, is most compatible with your camera system, and is rugged enough to stand up to your observing style.

Frithjof Sterrenburg lives in the Netherlands. His amateur astronomical interests are partially a result of his career in optical instrument design.

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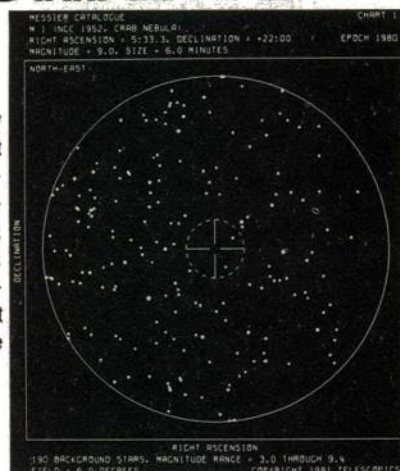
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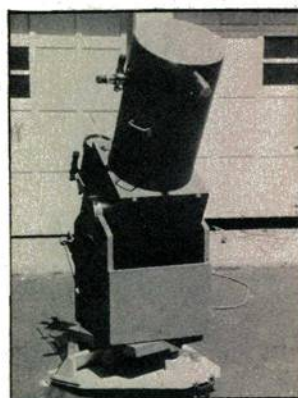
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the next supernova

by
Fred Schaaf

There is a reasonably good chance that many people alive today will see the next supernova. That star of stars will illuminate not only the heavens, but also our understanding of stars and stellar evolution as no other natural event could. That one flash, and its glimmerings after, will teach us vastly more about all stars.

But even the immense harvest of knowledge we could gather from supernova-light might not, by itself, be the greatest benefit. A supernova could also strike straight through to the heart of all great intellectual adventures: let's call it, in this context, wonder.

Recent historical research has revealed eyewitness accounts of brighter and more wondrous supernovae than were previously known. Many of us who are interested in astronomy have read about the classic supernovae. There was Tycho's Star, the supernova of 1572, and, in 1604, Kepler's Star — as well as the 1054 supernova which gave birth to the Crab Nebula. To these famous objects, scholars have added another half dozen supernovae which were unverified or unknown to modern astronomy just a few years ago. We now can construct a vivid picture of the coming of the next supernova.

The "new stars" of 1572 and 1604 peaked at brightnesses similar to those of Venus and Jupiter. Many people probably still imagine that a supernova in our galaxy would be much like having another Venus or Jupiter in our skies for a while. While having "another Venus" is certainly a marvelous prospect, it falls short of properly conveying the splendor of a star like Tycho's Star. More importantly, a galactic supernova at maximum might be an object of much greater brightness.

Of course, some historical supernovae were much fainter than the supernovae of Tycho and Kepler.

Large quantities of interstellar dust in our Galaxy have masked their true brilliance. If we could see it clearly, even a supernova on the extreme opposite end of our Galaxy would shine at a magnitude of +1 or +2. A few of these dust-dimmed supernovae

general public.

However, backyard astronomers would still view it with awe. They would know, even if it were fainter than Deneb or a bright nova, that this single star rivaled the combined light of a hundred billion suns. This gentle flicker would have utterly destroyed whatever planets might once have orbited it. Yet simultaneously we would know it to be a star gone to seed — a star brilliantly sowing space with heavy elements and the promise of new stars, worlds, and life.

But the historical record reveals that we are centuries overdue for a supernova. And not for just any supernova, but for a brilliant one. The lack of dazzling supernovae between 185 A.D. and 1006 might be the result of sparsely-kept records in troubled times. It may also reflect the paucity of modern astronomers who can, or have cared to, research and translate historical documents. The records of the 1408 supernova were identified in 1979 — and that one was apparently much brighter than Vega for at least a few weeks.

Furthermore, the study of supernovae in other galaxies also suggests that the present dearth may be unusual — or just a statistical fluke. Being "due" or "overdue" for this splendor certainly does not mean that a galactic supernova is guaranteed to appear in the next 20, 50 or even 100 years. We are dealing only with averages, and our data are still quite limited.

Still, the recurrences are encouraging, and we have a fair chance to see a bright supernova in our lifetimes. How bright? The historical record compels us to give rein to our imaginations, for at least twice in the Christian era there have been temporary stars which rivaled or surpassed the brightness of a crescent moon.

Just 48 years before the birth of the



Shang Dynasty
oracle bone that
may refer to a "new
star" near Antares.

have almost certainly been missed, especially before modern times, since even the diligent and dependable Chinese observers would not have seen a supernova peaking much fainter than +1.5 magnitude. If the next supernova is one of these cases, it will not be an impressive object to the



historical supernovae

Year of Appearance	Period of Naked-eye Visibility	Maximum Brightness	Location		Comments
			R.A.	Dec.	
			(1950)		
185 A.D.	20 months	-8	—	—	between α and β Centauri
386 A.D.	3 months	+1.5	—	—	in Sagittarius
393 A.D.	8 months	0	—	—	in Scorpius
1006 A.D.	24 months	-9.5	15h00m	-42°	in Lupus
1054 A.D.	22 months	-4.5	05h32m	+22°	Crab Nebula
1181 A.D.	6 months	0	02h02m	+65°	
1408 A.D.	4 months	-1.5	20h00m	+35°	probably Cygnus X-1
1572 A.D.	16 months	-4	00h23m	+64°	Tycho's Star
1604 A.D.	12 months	-3	17h27m	-22°	Kepler's Star
1680 A.D.	brief	+4	23h21m	+59°	Cassiopeia A

Crab Nebula, a star appeared which put the 1054 supernova to shame. In the spring of 1006, in the constellation Lupus the Wolf, a supernova reached a maximum apparent magnitude of -9.5 — roughly the brightness of a half moon. This magnitude estimate is based on eyewitness descriptions, especially those of its illumination of

supernova was Type 1 or Type 2. Type 1 is the rarer and intrinsically brighter of the two varieties of supernovae. The types have somewhat different light curves. If it were the more common Type 2 supernova, the star would have remained over -8.5 magnitude for about three weeks, and brighter than -7.5 for over three months. In all, it

greater than those caused by Venus or Jupiter. They would be different — phenomena which no bright planet or ordinary star could ever imitate. They would be unfamiliar to experienced observers and utterly new.

So let us then imagine that we are not just lucky, but are extremely fortunate. Let us imagine that the next supernova appears roughly as bright as the star of 1006. For convenience, we'll call it Lupus 2. With the aid of the eyewitnesses who actually saw the star in 1006, let us picture what the star would look like.

For the brief period of maximum brilliance, Lupus 2 would illuminate the landscape to the same degree as a half Moon. At night we would see distant objects. We could read the print of a magazine or newspaper by its light, and we would see some dim color in the landscape.

Lupus 2 would cause prominent shadows for several months. Under the right conditions Venus casts shadows, so a -4 magnitude supernova in a dark midnight sky (where Venus can never shine) probably could. Lupus 2, over one hundred times brighter, certainly would.

Lupus 2 will light up the sky. A half Moon considerably lights the sky and hampers our seeing faint stars near it. Lupus 2 would cause similar problems for observers of other celestial objects. But in this case, neither backyard astronomers nor professional astronomers would be likely to complain.

Reports on the Supernova of 1006

During the ninth year of Mokchong a "broom-star" was seen.

Koryo-sa, from Korea

This spectacle appeared in the zodiacal sign Scorpio. . . a large circular body, 2½ to 3 times as large as Venus. The sky was shining because of its light. . . .

All Ibn Rldwan, from Arabla

the landscape.

It was first spotted when it "only" rivaled Mars, which was then at opposition at about magnitude -2. In the next few weeks, the supernova burned steadily brighter and brighter until it outshone Venus — then brighter still — illuminating the sky about it. Then it became so searingly bright that its radiance literally spread across the entire sky.

We don't know whether the Lupus

would have remained distinctly more brilliant than Venus for around five months! Such a supernova would have been — and apparently was — visible to the naked eye for more than two years.

These figures are impressive, but they only take on their full force when we consider the individual observational effects produced by such brightness.

Such effects would not be merely

To truly appreciate these comparisons, go out on the next night the Moon is at First Quarter. But remember, what we have so far considered about Lupus 2 is comparatively tame. Only when we consider the differences between a supernova and the Moon or bright planets can we understand what staggering beauty will be unleashed upon us.

Like a star, the supernova will be a point of light. The light of the Moon, by comparison, is spread quite dully over a rather large area. But the supernova's brilliance will be intensely concentrated. Since a magnitude of roughly -19 has been shown in laboratory experiments to cause pain, Lupus 2 could be an excruciating beauty in even a small telescope.

The Moon is easily visible in the daytime sky, but the supernova would be far more prominent than the washed-out daytime Moon. On a clear day when Venus shines as bright as -4.0, it is quite visible to the naked eye. But it also may be hard to find because it is so small. A much brighter supernova would probably be spectacular in the day sky, and Lupus 2 would be hard to miss — like a constant bright glint of sunlight from the fuselage of a high-flying airplane. In the daytime, Lupus 2 would seem roughly as bright as Sirius does at night. Of course, day and night observing are not analogous in many respects — but consider that the great supernova of 185 A.D. was prominent enough that it was discovered from Lo-yang in China extremely low in the daytime sky. Perhaps the idea of Lupus 2 as a "Sirius of the daytime" is not an exaggeration.

Any extremely bright supernova would create cloud-coronae. Coronae are not halos, vast circles sometimes seen around the Sun and Moon; they are several degree wide colored areas which we see most easily when certain thin kinds of clouds pass in front of the Moon. Lupus 2, or even a less brilliant supernova, would surely produce coronae. These would probably be quite unlike the Moon's, and lovelier, because a stellar source would cause smaller, sharper colored bands.

Then there are effects caused by vision. While the concentration of so much light within a point would be beautiful, defects in the human cornea produce rays or spikes extending from bright objects. The brighter the object, the longer its rays appear. How big would Lupus 2 appear compared to Venus or Jupiter? How far would its rays extend? Fortunately we have the testimony of a very reliable witness concerning the size of the Lupus supernova. Ali Ibn Ridwan said the star appeared "two and one half to three times as large as Venus," meaning, of

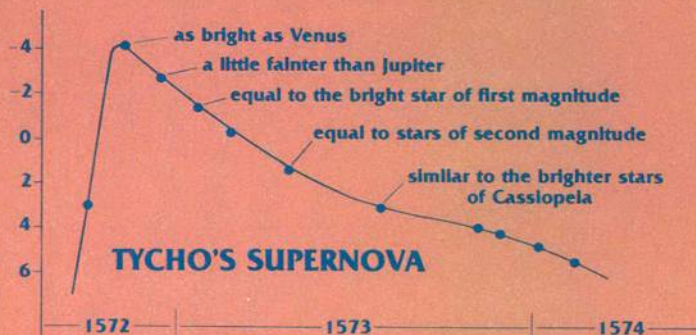
course, the diameter of its rays. Some of the finest observers of pre-telescopic days estimated the ray-spread of bright planets and stars. Their estimates suggest Venus has a ray-spread diameter of 3 minutes of arc — a figure we can verify. The 1006 supernova was as large as 7.5 to 9 minutes of arc — a quarter to a third the apparent diameter of the Full Moon.

But in this imaginative exploration of Lupus 2, we have neglected one property which supernovae share with stars but not with bright planets and

brighter than Venus! With rays 9 minutes of arc across, it would throw off a spectrum of colors, shine as bright as a half moon but far more intensely, and challenge the wildest imagination.

Try to picture supernova-rise. Even the murkiest atmosphere could not quell the radiance of such a star. It would be an endlessly dancing and varying mass of fire, shooting spears of intense color every way, a fountain of starlight heaved in one many-waved leap over the gap of several thousand light-years.

More striking than the Moon as it



Tycho Brahe on the Star of 1572

When on the above mentioned day (November 11), a little before dinner. . . I was returning to that house, and during my walk was contemplating the sky here and there since the clearer sky seemed to be just what could be wished for in order to continue observations after dinner, behold, directly overhead, a certain strange star was suddenly seen, flashing its light with a radiant gleam and it struck my eyes. Amazed. . . I began to doubt the faith of my own eyes, and so, turning to the servants who were accompanying me, I asked them whether they too could see a certain extremely bright star when I pointed out the place directly overhead. They immediately replied with one voice that they saw it completely and that it was extremely bright.

the Moon. Any star seen through the Earth's atmosphere twinkles.

Now perhaps we can begin to understand what awaits us.

In the magnitude step from Vega to Sirius, we see a wonderful increase in twinkling and color-flashes. Think of the scintillation and darting rays of color which you can see around Sirius with a small telescope, especially when Sirius is low in the sky. Now imagine the leap to ten times brighter — let it rival Venus in brightness. That's a -4 magnitude supernova. It would hardly be just "another Venus or Jupiter."

But Lupus 2 would be 100 times

rose, Lupus 2 would gain power and flood observer and landscape with pulsing illumination. On the ground, tossed flocks of racing shadow bands — those strange strips of shade seen for a brief time just before or after some total eclipses of the Sun — would animate the landscape. At latitudes where the star was always low, or on very turbulent nights, the shadow bands might rove eerily through forest and town from dusk until dawn.

Its mad scintillation, its dancing shadow bands and changing cloud-coronae would be almost frighteningly strange and awesome. A bright



supernova would be like a total eclipse of the Sun or the most striking of conjunctions — but the drama would last many times longer.

And what about combining the drama of a changing conjunction or occultation with the supernova? Supernovae are likely to be not far from the Milky Way in our sky. What are the chances for one being near enough to the ecliptic to have conjunctions with planets or the

scientific value.

Perhaps it would be close to the Sun. Imagine Lupus 2 rising just before dawn. And what would it be like to see a dull yellow-grey lunar crescent overwhelmed by a star? Or the edge of a crescent Moon occulting Lupus 2, instantly plunging the night into a second darkness? Even if Lupus 2 grew to brilliance beside an ordinary star, it would be magnificent. The 185 A.D. object shone just a few degrees from

of the brighter versions, it would be the most staggeringly beautiful heavenly object we can imagine. And we shouldn't forget that about once in 200,000 years there could be a star, a supernova, with a magnitude of -14. There is some evidence that a supernova roughly as bright as the Full Moon (-12.5) greatly influenced early civilization around 4000 B.C., and created the Vela pulsar.

To judge from history, a -7 magnitude supernova might only occur about once a thousand years — but a millennium has nearly passed since the last one reached that brilliance. What kind of impact would a Lupus 2 have on the people of this world?

What a shame that the splendor of such stars in the past was so quickly forgotten. Perhaps the next supernova will also shine unheeded, in bitter beauty over a desperate or deserted world.

But perhaps it will be noticed and will kindle a sense of wonder throughout the world. This time, the "guest star" could be seen, photographed, painted, shared, studied, enjoyed — and never forgotten. When the next supernova appears in the heavens, we might be ready.

During the third year of the Ching-te reign period, a huge star was seen at the west of Ti. Its bright rays were like a gold disk.

Yu-hu-ch'ing-hua, from China

Moon?

No less than three of the seven verified supernovae lay in the Zodiac, and at least two were involved in close conjunctions. The Crab supernova appeared next to a crescent Moon, and Kepler's Star placed itself in a conjunction with Mars, Jupiter and Saturn. Its location actually led to this supernova's discovery while it was still on the rise. Today, an early observation would be of tremendous

Alpha and Beta Centauri.

Even if our next supernova is dimmed by interstellar dust, it will be intensely interesting. Even if it is in the medium range of brightness, it would be the loveliest point of light in the heavens for quite a while. It would probably be even more satisfying than the great comets, which do not stay long at their brightest and most long-tailed.

But if our next supernova were one



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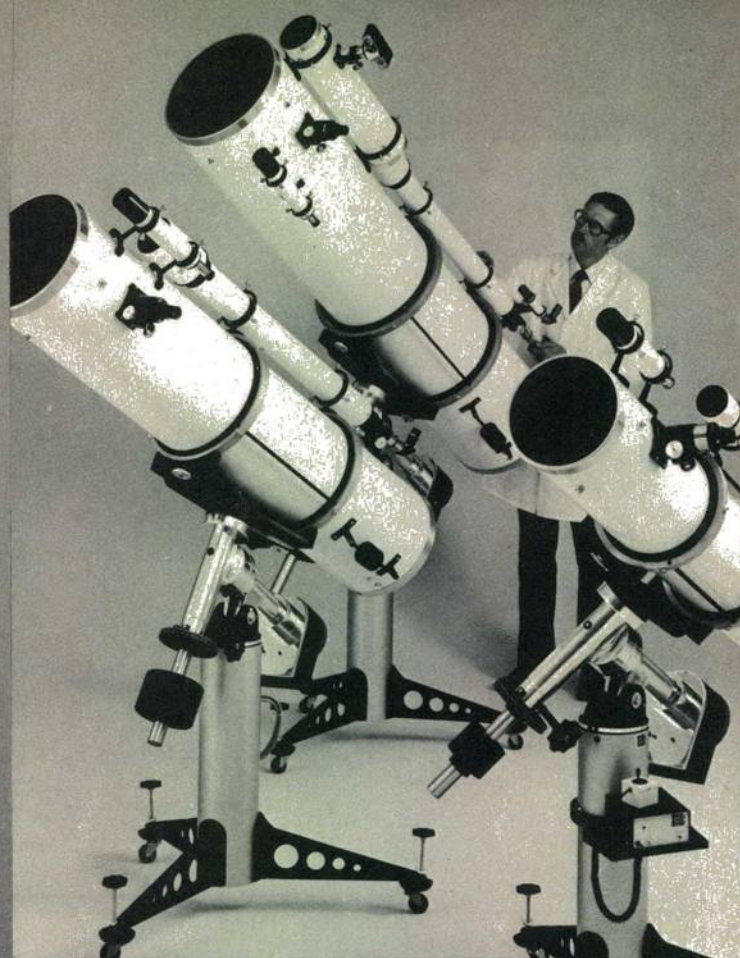
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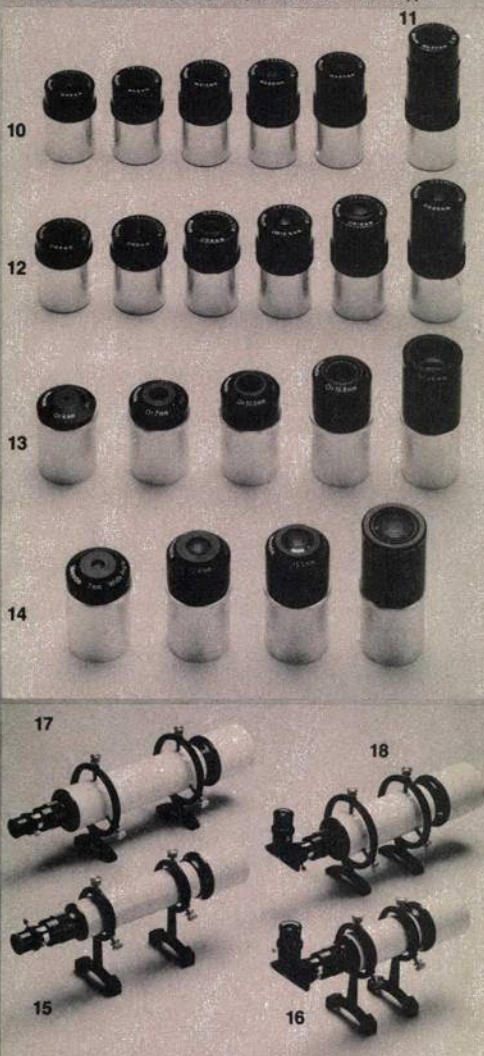
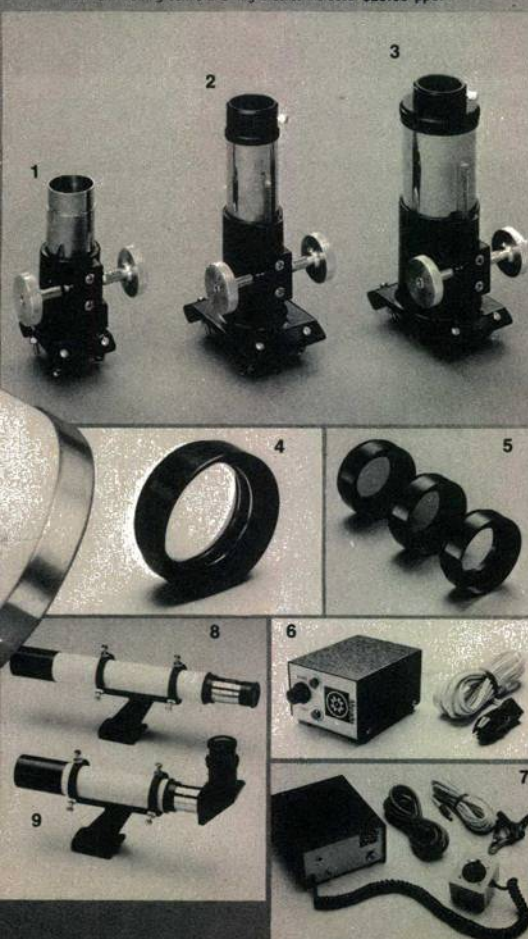
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Every day, envelopes filled to the brim with photos, slides and observational reports pour through the mail slot at *ASTRONOMY*. We keep a great number of them on file for future use, and send an even larger number back to the photographers. Although we can't print every picture we accept, we wish we could. Sometimes there just isn't enough space.

But every so often we get deluged with good pictures from current celestial events that deserve to be showcased in *ASTRONOMY*. We think you should see them, so we've made space for some of them on these pages.

The number of people engaged in astrophotography today indicates a blossoming enthusiasm for the hobby. And recent advances in film and lens technology have put high-powered tools formerly relegated to the professional observatory staff into the hands of backyard observers. This combination — enthusiasm plus technology — bodes well for astrophotography.

Several major astronomical events highlighted 1981, and clear weather permitted a record number of good photographs. The lunar eclipse in July, the total solar eclipse, the Perseids, and a continuing array of planet groupings in the twilight sky were some of the best.

The photographs on these pages represent varying levels of difficulty and skill. Some are simple, unguided photographs taken with a stationary camera; others are composite images of several negatives combined in the darkroom to produce one spectacular photograph. Whatever the method, the message is clear — backyard astrophotography has come of age.

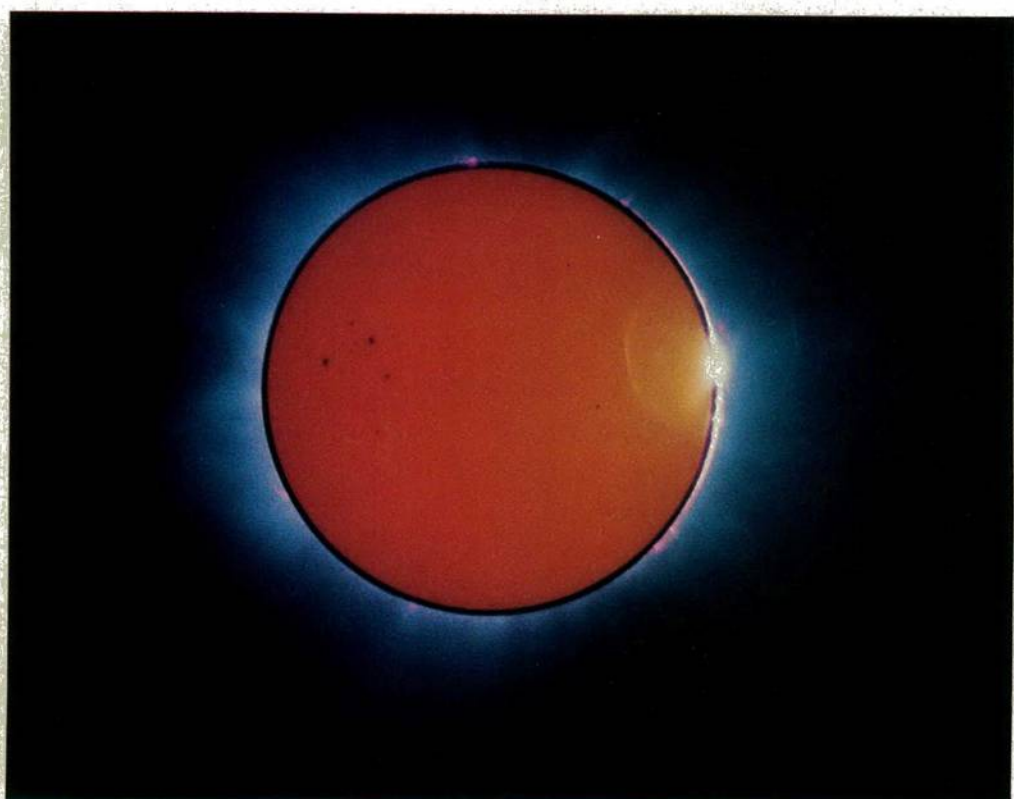
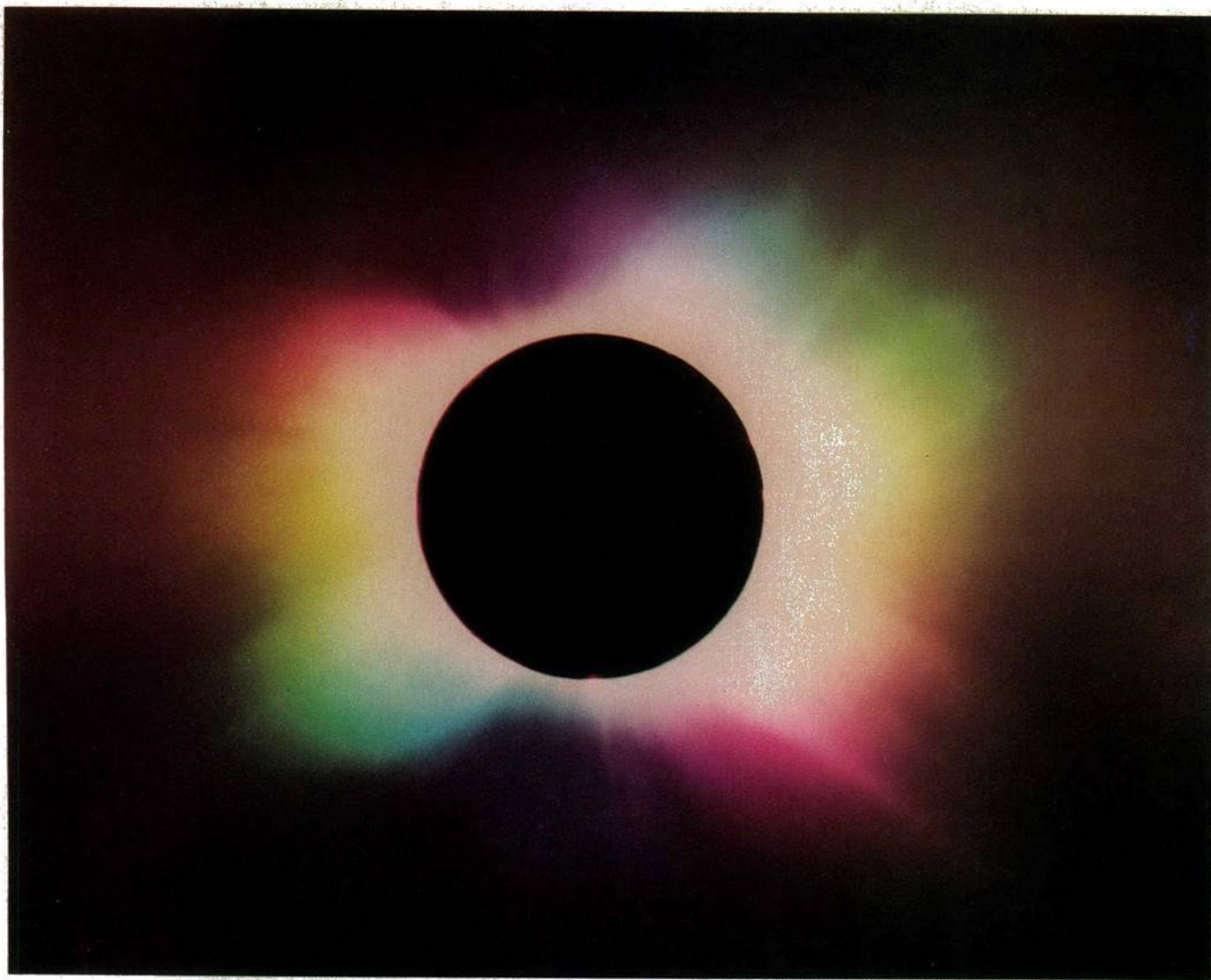
We chose these photos to give you an idea of what some observers are doing with the medium. None of them are professional photographers, but

some of the techniques they use indicate a high level of knowledge of both film and darkroom techniques. Anyone who can produce an eight-negative composite color image in a home darkroom should be applauded. And though many photographers work in less than professional surroundings, their results rival those produced by professionals.

This doesn't mean that only those who use advanced techniques will be published. One of our favorite choices is a simple unguided photograph of one of the many conjunctions that occurred over the past year. It is one of the easiest of all astrophotos to make, requiring no complicated gear, but it is also a better photo than many we

Two eclipses — a solar and a lunar — helped relieve summer boredom for observers and astrophotographers. The colorful coronal photograph (upper right) is a darkroom composite of eight Kodacolor II negatives taken with a 775mm f/6.3 lens using 2 and 6-second exposures. A polarizing filter rotated at four different angles produced the rainbow hues of the corona. A dual-image "sandwich" print (below right) shows the solar disk before first contact and the corona two seconds before totality. Both photos by Wendy Carlos and Annemarie Franklin. Below, A.W. Steinbrecher used a 16-inch f/5.5 reflector to make this $1/125$ -second exposure of the partially eclipsed Moon. Following pages: The Moon, Jupiter and Saturn posed for this 7-second unguided shot captured on ASA 64 film. Photo by Jerry Schad.











The ever-popular Perseids may be the most photographed meteor shower on record. The top photo shows a 6-minute guided exposure made with a 50mm lens at $f/2$ on Fuji 400. Photo by Jack Brisbin. At left is a 15-minute unguided shot of a Perseid in Lyra taken through a 50mm $f/1.4$ lens and recorded on ASA 200 film. Photo by S. Presnell.

received, because the photographer took the time to plan his shot and included some interesting foreground elements to enhance the composition. It's not too tricky, but it did require some forethought.

Astrophotography is still a highly specialized art, and not many people are very good at it. We can, however, learn from those who are: Take your time. Think ahead about what you want the image to show. Then determine a way to produce it.

All these photographs were made with common telescopic and photographic equipment in the careful hands of experienced observers. That is what made the difference. The results you get will only be as good as the time you spend planning them. Who can afford to waste film nowadays anyway? We hope you'll enjoy this round-up of astrophotographs. — *Berry Brunk*

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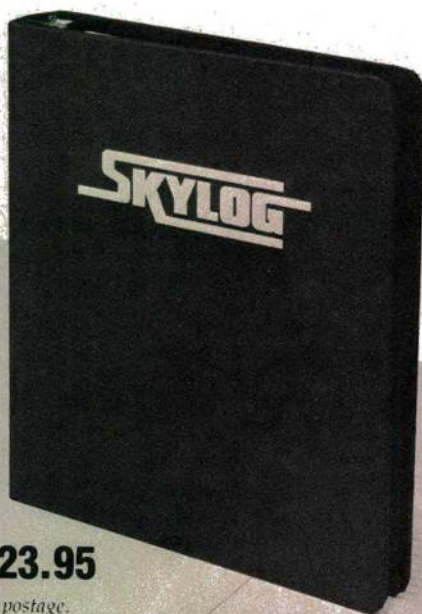
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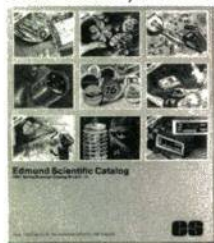
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Imagine for a moment walking into a room in your house, dimming the lights, and watching stars magically appear where the ceiling used to be. Sounds like a planetarium, doesn't it? Actually it isn't, but the effect produced by this artistic illusion is so similar to the sky of a good planetarium that it's almost like having one in your home. These private celestial spheres have begun to dot the country as amateur astronomers combine their artistic skills and astronomical knowledge.

By using a special paint and a template process, you can paint the entire night sky, complete in every naked-eye detail, onto any ceiling in your home — and it's invisible when the room is lit. When the lights are turned off, and this paint is exposed to sufficient ultra-violet radiation, the entire mural glows for a half hour. Opticians, lawyers, sailors, and planetarium educators — as well as backyard astronomers — are just a few of the people who have customized their ceilings with a map of the heavens.

Sounds like a good idea, right? Well, it is easier said than done. Anyone who has spent 20 hours standing on a ladder and looking up will tell you that. Clearly this is not the project for weekend handymen. When it is done step by step and with patience and skill, this pseudo-planetarium is a work of art that will give many years of fine "naked-eye observing" from the comfort of your favorite chair.

How do you do it? First, choose a room that you use for relaxation, such as the living room, or better yet, the bedroom. The main criterion is that the room has to be made dark — very dark. Therefore, rooms with easily blocked windows are preferable, because you may even want to look at your night sky during the day.

Now for the catch. You'll need special luminescent paint to pull off

this trick. This paint is available from many commercial silk screen supply sources, but since it isn't advertised and has no trade name yet, you will have to hunt down a supplier in your area. The cost is moderate — \$6 per quart. Although you won't use an entire quart, you might want to buy additional colors.

The paint is particularly sensitive to ultra-violet radiation. Under a black light it will glow brightly, but looks very natural when put on the ceiling as star-like points. It is water soluble, and can be cleaned up easily with soap and water.

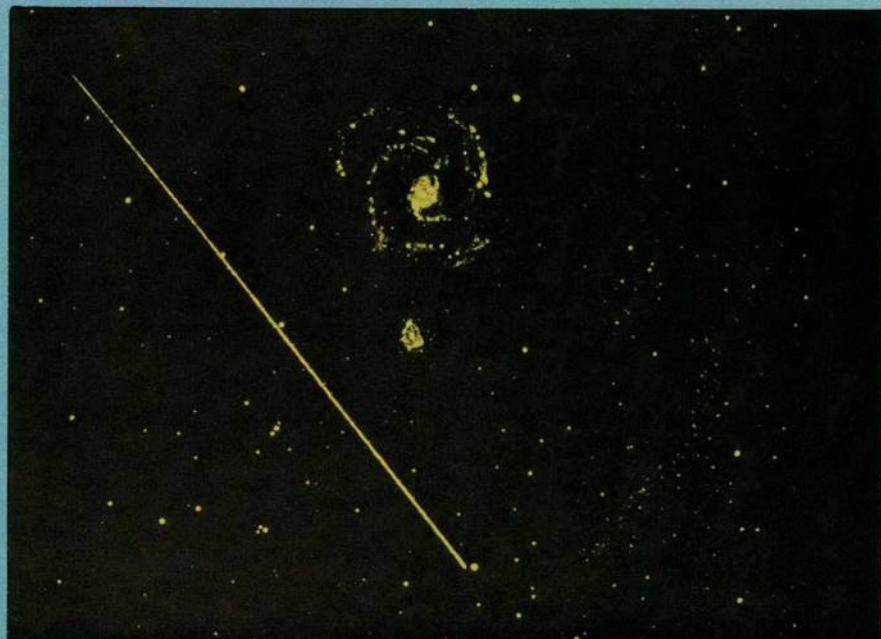
Once you are ready to begin your imitation of Michelangelo in the Sistine Chapel, get out your best star charts and turn on your black light. Start with Polaris and make it a small dot about 5mm in diameter. This will be your reference point and its placement is arbitrary depending on

what constellations you decide to showcase. Now complete the rest of the Little Dipper making your star dots close in size to their apparent magnitude. Once you've finished, move on to the Big Dipper and so on, star-hopping as you would to locate deep-sky objects.

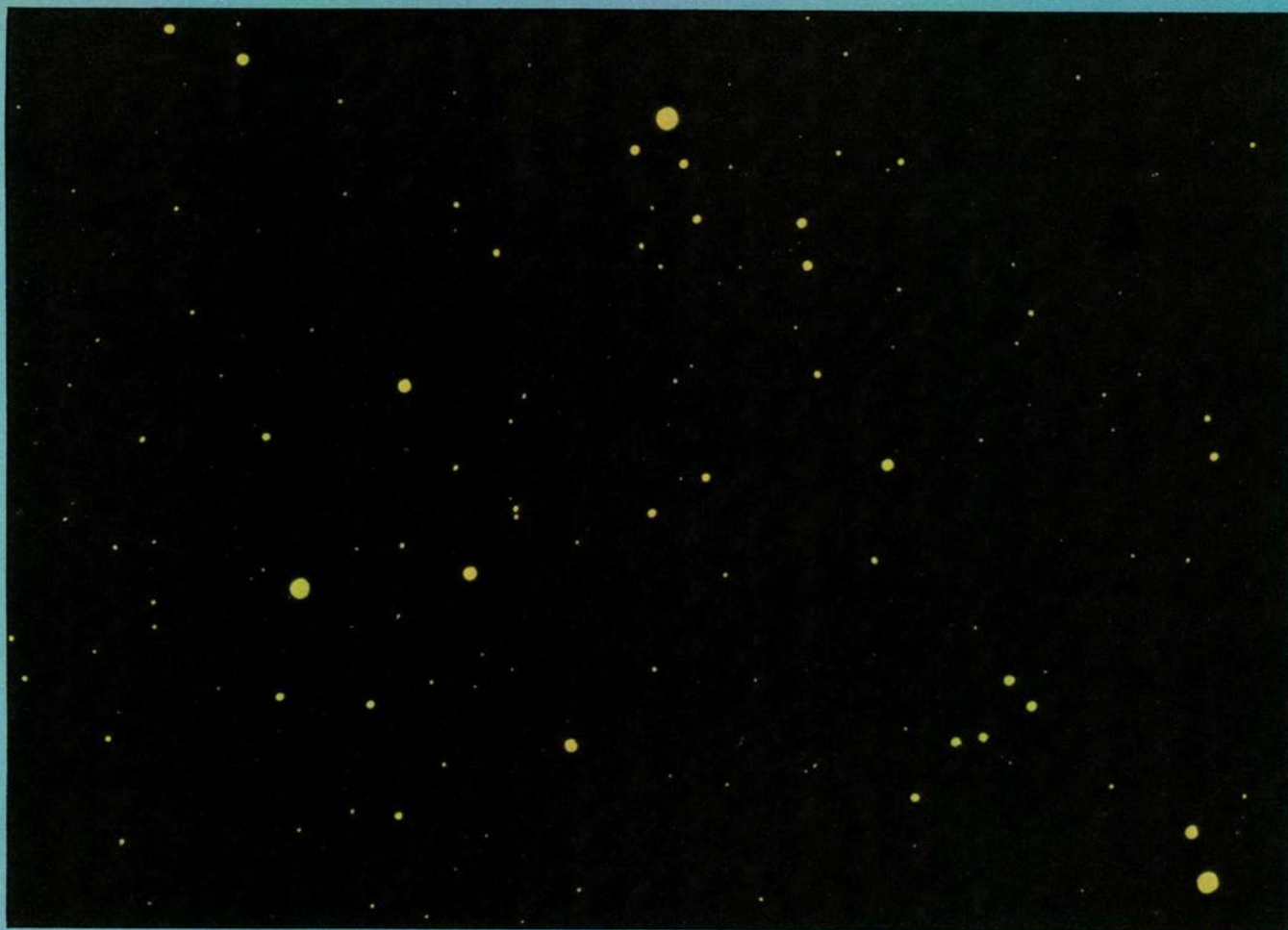
Concentrate on painting the bright stars exactly where they appear in the sky. Keep the constellation's outlines apparent and don't burden the effect with too many fainter stars. Remember, the familiar shape of the constellations is the most important part of the mural's illusion.

Once you've finished your circumpolar work, move on to the seasonal groupings and put them up in the same fashion. It should take about four hours to do each major grouping — winter, spring, summer and fall. Take your time — don't overwork yourself and become frustrated. This is

A PAINTED WHIRLPOOL COMPLETE WITH A METEOR







Standing on a ladder and reaching upward for hours can be a literal pain in the neck, but you'll have to do it to get good results like these. Above is the combined area of the Summer Triangle featuring Lyra, Cygnus and Aquila as painted in an astro-mural. Both pictures are 7-second exposures taken through a 28 mm lens and recorded on ASA 200 film. Photos by J.M. Woodland.

a long-term project, and your patience will pay off in the end if you take great pains to match the precise positioning of the heavens.

An artist in Virginia who has completed nearly twelve star murals recommends using templates with the constellations' main stars punched out. Placing these on the ceiling provides a guide for the actual painting, and every ceiling done with them is a nearly perfect replica of the night sky.

Once you have the main constellations down — or up, actually — put in some of the lesser known configurations. One recently completed mural contains 60 of the 88 constellations visible from both hemispheres — all on one bedroom ceiling.

After your first bout with ceiling painting, you'll probably feel a little like Michelangelo did when he wrote

his poetic complaints to the church. But now comes the reward. When you turn off the black light, the initial effect is tremendous. Your ceiling will glow its brightest and resemble the night sky as seen from the Mojave desert. As the tiny drops of paint lose the energy they stored during exposure to the black light, they will dim and appear more and more natural. They fade rapidly at first, but then reach a plateau that closely approximates the appearance of the night sky from a dark suburban location.

As your personal sky continues to fade, it will take on the appearance of approaching dawn. Many people put the painting in their bedroom, so they can watch the stars and calmly drift off to sleep.

Now that you've painted the constellations, it's time to add the filler — the countless small dots that will duplicate the nebulous glow of thousands of 6th magnitude stars. Just take your paintbrush and tap lightly all over the ceiling. Make sure you put in enough to make it look convincing, and follow the star chart as much as possible — though certainly not for every dot. Some murals contain more than 5,000 carefully placed stars. You can make yours as detailed and accurate as you like.

Now you're ready for the big

surprise. Bring over some friends who weren't aware you were working on this. Seat them around the room and have them close their eyes — you can tell them it's for dark adaption.

Then, turn on the black light and let it "charge up" the ceiling. If you have an electronic flash, use it to intensify certain spots. After a couple of minutes, cut off all the lights and instruct them to open their eyes and look up. Although you won't be able to see the look of amazement on their faces, you can bet it's there. A few seconds of hushed silence will precede a deluge of questions about how they can get their own night sky. The effect is so real that almost every sky lover who has seen this type of painting wants one.

The total cost for producing a 12' x 12' ceiling mural will only come to around \$15 if you do it yourself. But the effort will cost you some evenings and weekends. You'll have to study the constellations and their relationships to each other more carefully than you ever did before and then plot them on your ceiling. Take your time and make it as accurate as possible. You'll be rewarded after it's finished when you have an exact replica of the sky in your house — one that is dry and warm and can never be clouded out.

— Berry Brunk

AstroNews

U.S. Planetary Program Could Be Cut Entirely

The Reagan administration is seriously considering eliminating U.S. space exploration from the federal budget, planetary scientists have recently learned.

Dr. David Morrison, chairman of the American Astronomical Society's Division for Planetary Sciences, has announced that the planetary program might

be canceled to meet the White House goal of full funding of the Space Shuttle, while at the same time cutting the overall NASA budget by 15%.

"Given its tremendous boost to national pride and prestige, many people don't realize that the entire planetary program uses only three percent of NASA's

budget, and all NASA expenditures are still less than one percent of the federal budget," Morrison said. "Yet, this highly successful effort is to undergo more than a belt tightening. It may be killed outright."

Reagan-appointed NASA officials are negotiating with the White House in hopes of saving the planetary program.

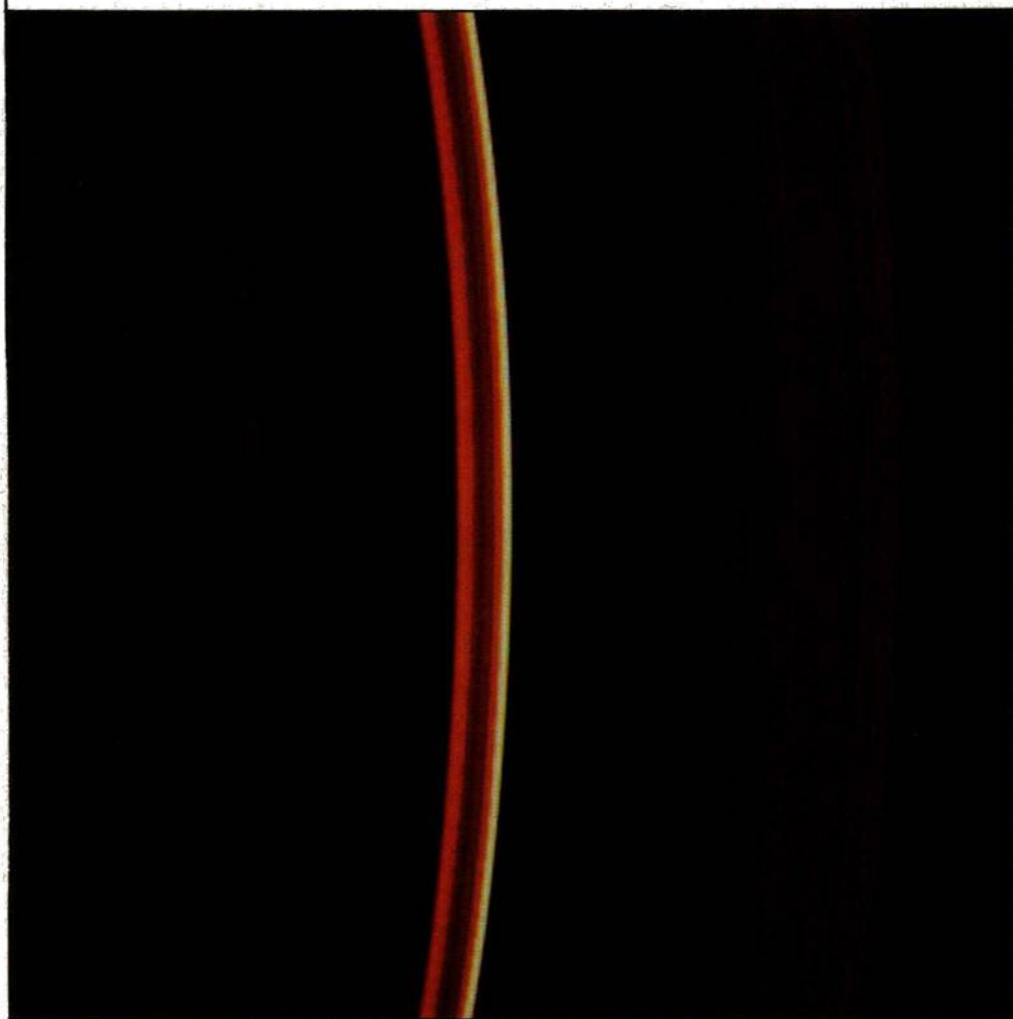
"If the Administration goes through with the tentative White House plan, and Congress passes it, the phase-out of the planetary program would begin a few weeks from now," Morrison said.

Such cuts will mean the immediate cancellation of Project Galileo, the spacecraft scheduled to orbit Jupiter late in this decade and the only deep-space probe approved since the Voyager Mission. Nearly \$300 million has already been spent on Galileo. Proposed new missions, such as the radar exploration of Venus and a visit to Comet Halley, will be out of the question. Russian, Japanese, and European space probes to that comet will leave the U.S. far behind. Morrison reports that the Voyager probe, now enroute to Uranus, may simply be shut down and silenced.

This grim news reached scientists just as they began reporting the spectacular results of Voyager's encounter with Saturn, at the Division for Planetary Sciences meeting held October 13-16 in Pittsburgh, Pennsylvania. In addition to a major science report to the public, the meeting included a special session on Science and Public Policy. Representatives from Congress, the Administration, and the scientific community had been invited to discuss what public policy should be for basic research and exploration.

Before the recent budget crisis, NASA Administrator James Beggs, a Reagan appointee, had voiced pride in the successful Saturn encounter at a press conference at JPL on the day of the closest encounter: "This nation, when it puts its mind to it, can do splendid things. It is a source of great pride to me."

Beggs stated that NASA had a definite list of priorities in approving space science projects: first the Space Telescope, next the Galileo mission to Jupiter, then VOIR,



When the Voyager 2 photopolarimeter tracked the star Delta Scorpii through the rings of Saturn, the star's light was blocked for varying intervals depending on the thickness of ring material. This image (reconstructed from Voyager 2 data) shows the ring structure in the outer C ring, and a central ringlet with thick ridges at its edges.

At the polarimeter's highest resolution (100 meters), the F ring also shows a similar double-ridged structure in its densest strand. This frame covers an area about 600 kilometers wide — the smallest details in it are 1 kilometer across. Photo courtesy of Larry Esposito, University of Colorado Laboratory for Atmospheric and Space Physics.

a geology mission to Venus. Lowest was the International Solar Polar mission, a two-spacecraft, joint NASA/ESA project. The United States has subsequently canceled its half of the mission over strong protests from the European Space Agency.

Commenting on an American mission to Comet Halley, Beggs said, "We've got time to look at the options, but let's not just 'me-too' it. If we can afford to do it, we'll do it."

Defending the priority role

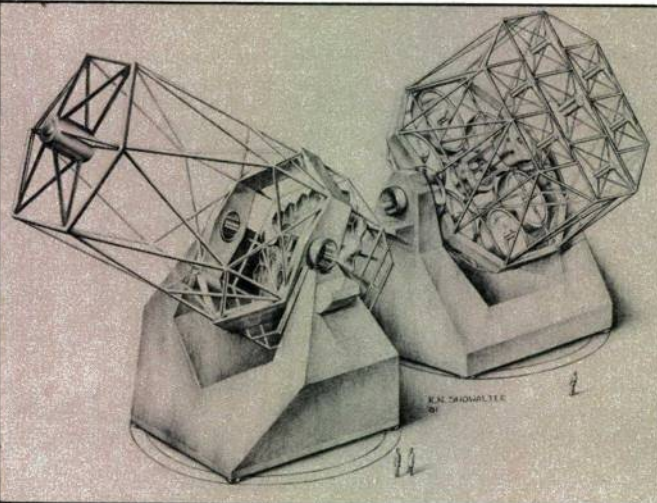
of the Space Shuttle in the NASA budget, Beggs said, "Shuttle has no more military uses than any other launch vehicle. It could all be done with expendable vehicles."

Said Beggs, "We are now completing what has been a really enormous space program. It would be nice to go back and have the kind of budgets we had in the late '60s, but this Administration has a very clear idea of what they're about — and that's reducing the federal expenditure."

born out of clouds of gas and dust. The telescope is ideally suited to follow-up observations of distant objects

detected by other facilities such as the Space Telescope and the Very Large Array Radio Telescope.

Two designs for Kitt Peak scope.



Kitt Peak Bends Mirrors for World's Largest Scope

A telescope development team at Kitt Peak National Observatory has begun the final and most critical stage of a full-scale test to make astronomical mirrors with a radical new manufacturing method. The team will polish two precisely matched, parabolic mirrors — each nearly eighty inches across — that could form part of a much larger assembled mirror.

"The successful completion of these mirrors," said project scientist Donald Hall, "will be a major step in proving that we can build a giant telescope which will combine the light from one hundred individual mirrors. The resulting light-gathering power will be equivalent to a single conventional mirror measuring almost fifty feet in diameter but at a small fraction of its cost."

The 15-meter telescope will have more than six times the light-collecting area of the Soviet Union's six-meter telescope, and nine times that of the Palomar 200-inch.

"Conventional optical manufacturing methods simply cannot produce such mirrors in a reasonable time at an acceptable cost," said Project Engineer Larry Barr. "Instead we have adopted a new approach — stressed mirror polishing — in which the glass mirror blank is carefully bent to a pre-calculated shape, and held there while an easy-to-polish spherical surface is produced. It is then released to spring back to its original unbent condition, transforming the spherical surface into the desired off-axis paraboloid in the process."

This huge mirror requires

powerful bending forces that must be carefully controlled with a special mechanical fixture to avoid breaking the glass. The true optical focal length of each mirror — a distance of almost one hundred feet for the fifteen-meter telescope — must, in contrast, be measured to a precision of a few thousandths of an inch.

"This project is the next step in Kitt Peak's plan to provide the nation's astronomers with a capability that has tantalized the world in recent decades," explains Observatory Director Geoffrey Burbidge. "Conventional telescope designs simply cannot be scaled to this size range and so, during the 1970s, the Observatory's Next Generation Telescope program studied many novel concepts for building a giant telescope. By 1980 there was general agreement that the telescope should be one of two types: either a segmented mirror telescope with a single mirror assembled from smaller segments, or a multiple mirror telescope which combines light from six or more commonly mounted telescopes."

The new telescope will look deep enough into space and time to study in detail the light emitted by galaxies which are still forming. Understanding the early stages of galactic evolution is critical for establishing the dimensions and geometry of the universe.

The telescope's light-gathering power and its ability to resolve objects emitting infrared radiation will also provide an enormous jump in our ability to observe stars and planetary systems being

Palomar Sky Survey Gets Detailed Treatment

Imagine a road map without names, symbols, or numbers and you'll get a vague idea of what astronomers have been using for years to find their way around the sky.

At nearly every major observatory in the world, one of the key tools in use is a collection of large photographs, each resembling a child's spatter paint picture more than a portion of the night sky. The drawback to this famous collection, the *National Geographic Society-Palomar Observatory Sky Survey*, is that each of its more than 1800 photographs is just that — a photograph with no markings or names or other information explaining its content. Each print simply contains hundreds of black dots and shapes, some large and some small, on a white background.

Now, Robert Dixon, assistant director of the radio observatory at Ohio State University, has added names

and numbers and countless details to this sky survey, producing a set of corresponding overlays for use with the Palomar prints that take the chore out of using them.

The overlays are simple. When one is placed on top of its matching print, the dots and shapes lose their anonymity. All major objects are identified on the overlay.

While the idea of the overlays is new, the information they carry has been available for years. It took Dixon five years of "detective work" to put it all together.

This is the first all inclusive catalog of known astronomical objects produced since the turn of the century. J.L.E. Dreyer, a noted astronomer, produced the *New General Catalogue* in the early 1900s, but it only contained about 15,000 objects — a mere fraction of those identified by Dixon.

NASA Researcher Solves Computer Imaging Problem

A problem that has confounded computer graphics experts since computer-aided designing began has been solved by mathematician David Hedgley

of NASA's Dryden Flight Research Center, Edwards, California.

The problem was that a computer does not "see" a solid object the way a human

sees it, but defines the whole object at once without regard to a particular perspective.

Consequently, when asked to produce a picture of an object, a computer would show all of its surfaces, angles and curves regardless of whether they are on the side facing the viewer or on the back. This resulted in cluttered, confusing and ambiguous pictures.

Hedgley's solution permits the computer to depict an object from a specific viewpoint just as the eye would see it. The solution also works with any object or group of objects, no matter how complex.

Mathematicians have worked on the problem for years, and some achieved partial solutions. But until Hedgley's new program, none could be applied to any three-dimensional scene, and few were accurate. In fact, specialists considered the hidden-line problem the most difficult in the field.

Hedgley's program has just undergone computer testing which verified the solution's

workability with respect to speed, accuracy and range of application. The speed is surprisingly high. Previous solutions broke down when dealing with complex scenes because execution time increased with the square of the number of polygons. Hedgley's solution avoids this problem, so it is not hampered when rendering complex objects.

Researchers use Hedgley's solution in aircraft experimentation, and are finding it highly effective for analyzing wing flutter problems in unsteady aerodynamics. They have also created simple structures on small computers and expect to expand this into simulated aircraft flight — a task requiring a more sophisticated computer. Such simulated flight enables a pilot to practice chasing a synthetic target airplane by watching the image on a TV-like cathode ray tube. Speed becomes an essential ingredient in this sort of exercise, where the program must be rapidly executed.

Shuttle Project Winners Meet with NASA Scientists

The 10 winners of the first Shuttle Student Involvement Project discussed their Shuttle experiment ideas before NASA scientists and engineers recently at Kennedy Space Center, Florida.

The competition, a joint venture of NASA and the National Science Teachers Association, was aimed at stimulating the study of science and technology in grades 9 through 12 through a competition to develop experiments for use aboard the Space Shuttle.

Since their selection in May (see *AstroNews*, September 1981, p. 61), NASA has sought commitments from U.S. industrial firms and other groups to sponsor the student winners and assist them in transforming their proposals into actual experiments ready for flight.

The sponsors have been asked to assign a company scientist to work with the student, and provide funding for student travel, hardware development and costs related to pre and post-flight analysis and reporting.

A NASA field center scientist will act as a consultant to help develop

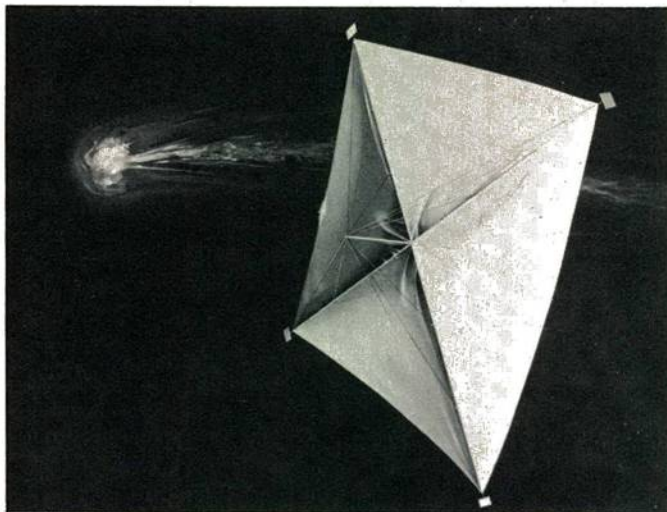
and integrate each student's experiment for eventual inclusion on a Shuttle flight.

Most of the experiments will be placed in stowage lockers in the mid-deck section of the Orbiter. All experiments proven suitable for flight have a commitment of one hour of an astronaut's time to perform necessary operations to conduct a successful experiment.

All data from the student experiments will be in the public domain and made available from the National Space Science Data Center at NASA's Goddard Space Flight Center, Greenbelt, Maryland.

The second Space Shuttle Student Involvement Project contest begins February 1, 1982, with regional conferences set in March and winners selected in May.

Students who are interested in submitting experiment proposals should have their teachers write for an official entry form and rule booklet. Teachers should address their requests to: Space Shuttle Student Involvement Project, National Science Teachers Association, 1742 Connecticut Ave., N.W., Washington, DC 20009.



Proposed solar sail. NASA photo.

Solar Sail Under Study for Space Transport

Modern day adventurers — much like the pioneers who sailed clipper ships and guided prairie schooners to resources beyond the horizon — are now at work on a new means of transportation: the Solar Sail.

Development of this energy-efficient means of space transportation that uses a leafy thin, reflective mylar surface to tap solar energy and propel its payload is underway by engineers at the World Space Foundation in Pasadena, California. An experimental launch of a Solar Sail could take place in 1984, debuting a promising technology for future commerce, resource retrieval, and exploration of our final frontier. The project staff has completed the sail fabricator, and the first prototype sail is under construction at NASA's Jet Propulsion Laboratory.

Funded by the World Space

Foundation, a private, non-profit corporation, the initial mission is projected to cost \$1 million — relatively inexpensive for a space project. Public response to this project has been encouraging.

The Solar Sail Project is conducted in cooperation with the Jet Propulsion Laboratory and supported in part by the Charles A. Lindbergh Fund along with donations from individuals and corporations. Former JPL engineer, Jerome Wright, is solar sail project director. Author Ray Bradbury is an active lecturer and consultant for the foundation. James R. French, manager of advanced planetary studies at JPL, serves as projects director.

For further information contact: World Space Foundation, P.O. Box Y, South Pasadena, CA 91030; or call Kristan Lattu at (213) 354-7106.

Weather Data System Could Trim Jet Fuel Expense

With little more than fine tuning of global weather forecasting apparatus, the worldwide commercial airline industry could save more than \$1 billion in annual fuel expenditures, according to a NASA study.

Robert Steinberg, project manager of the NASA Commercial Aircraft Fuel Savings Program, said a 20-month study indicates that "with detailed and timely

reports on winds at altitudes from 4,500 to 13,700 meters, commercial carriers could save as much as \$1 billion each year in fuel costs, while savings in the United States would reach \$100 to \$200 million annually."

The program's goal is to unite the best of man and machine to provide a weather data base to commercial airlines for more accurate flight planning. By following

the reports, pilots could fly routes that take advantage of the most favorable wind and temperature conditions.

When the cost of fuel was low, completely automated weather forecasts with a wide-ranging view of the weather were adequate. But the awesome leap in the cost of fossil fuels since 1974 has caused all concerned to take a closer look at the subject.

The government-sponsored program has shown that many long distance flights are planned on old weather data — and much of the data is too broad to pinpoint the location and intensity of important upper air jet streams and regions of sharp temperature changes.

The commercial aviation industry now spends between \$36 and \$40 billion annually for fuel, more than 40 percent of the airlines' overall operating expenses. Whether a multi-engine jet aircraft bucks a stubborn headwind, or is assisted by a favorable tailwind, makes an enormous difference in fuel consumption.

Worldwide weather information is currently assembled automatically, fed into computers, and called up at will for flight planning purposes. But such information is usually based on weather observations taken at 12-hour intervals, and

airlines often plan their long distance flights on an 18 to 24 hour forecast. However, the weather, particularly over oceans, can change drastically in a 6 to 12 hour period.

To demonstrate the impact of wind on fuel economy, a commercial jet traveling at 800 kilometers per hour can cover 1,600 km in 120 minutes. Burdened with a 240 km/hr headwind, the plane's flight progress would be reduced to 560 km/hr and the distance would require 171 minutes to cover. Conversely, aided by a favorable, 240 km/hr tailwind, the plane's progress would be increased to 1,050 km/hr and it would require only 92 minutes to travel 1,600 km.

A 747 consumes 16,400 liters of fuel per hour. Thus, the 1,600 km flight hindered by a headwind would consume 46,645 liters of fuel, while the tailwind-assisted flight would require only 25,100 liters. This would save almost half the fuel. Multiply these calculations by the 400 to 500 commercial jet flights across the North Atlantic in a 24-hour period during the summer months, and the potential for savings becomes clear.

With utilization of these new forecasting techniques, an international carrier with current fuel expenditures of \$1 billion could save \$20 million a year on fuel alone.

and the matter around it becomes so hot it emits a brief burst of X-rays. (See "The X-ray Universe," ASTRONOMY, July 1977.)

If Aquila X-1 is a typical X-ray burster, then all X-ray bursters may be normal star-neutron star binaries. Ken Croswell.

Astronaut Candidates Complete Training

Nineteen NASA astronaut candidates and two European Space Agency (ESA) mission specialist candidates have completed the first phase of training at the Johnson Space Center, Houston.

The 19 Americans became full-fledged members of the U.S. astronaut corps, which now totals 79. Their continued training will qualify them for duties as pilots or mission specialists on future Space Shuttle flights. They began training in July 1980.

NASA agreed last year to include two Europeans in the training program in

recognition of the substantial contribution ESA is making to the Space Transportation System by funding the development of Spacelab. ESA is reimbursing NASA for the cost of training the two Europeans.

ESA has indicated it will decide soon which of the two it will transfer to NASA for payload specialist training in preparation for the first spacelab flight. The other trainee will continue as an ESA astronaut at Johnson for possible selection as a mission specialist for European payloads aboard the Shuttle.

Amateurs Own \$56 Million in Telescope Equipment

American and Canadian amateur astronomers today own \$56 million worth of telescopes that pack a total light-gathering power equal to 68 Mt. Palomars. Last year they added more equipment and accessories to this arsenal than could be bought by triple the budget of Kitt Peak Observatory.

Fantastic? This is the conclusion reached in a summary survey of North American amateur astronomy compiled by the Astronomical League Light Pollution Committee at the request of a group of the Lighting Engineers Society studying harmful impact of light waste.

Interest in astronomy as a serious hobby is widespread. An estimated 185,000 active non-professionals are among at least 400,000 who, the survey estimated, have "some interest" in the hobby. A recent university estimate, for example, put the number who have recently taken elective astronomy courses at about 200,000 people.

In the two countries there are 20,000 active amateurs organized in more than 400 local astronomy societies and clubs. About 60 percent of these are affiliated with national or regional groups

such as the League or the Royal Astronomical Society of Canada.

The total U.S. annual market for imported and domestic instruments may be more than 40,000 units, including at least 15,000 produced here — and several telescope industry executives have stated that these figures may be low.

Amateur astronomers make significant contributions to the science. Probably 500 observers provide data to six specialized societies which, in turn, make it available to professional researchers.

The study also mentioned the cultural benefits of this popular science and the costs of continued degrading of the quality of the dark sky. The report cited a United States Environmental Protection Agency study of the daytime sky which stated, "Decreasing visibility of the sky creates aesthetic and psychological costs, loss of property values, loss of tourist revenues in scenic areas and general citizen dissatisfaction."

For a copy of the summary report send a stamped self-addressed envelope to: Astronomical League Survey, 329 South Front Street, Harrisburg, PA 17104.

X-Ray Bursts Discovered from Aquila X-1 Source

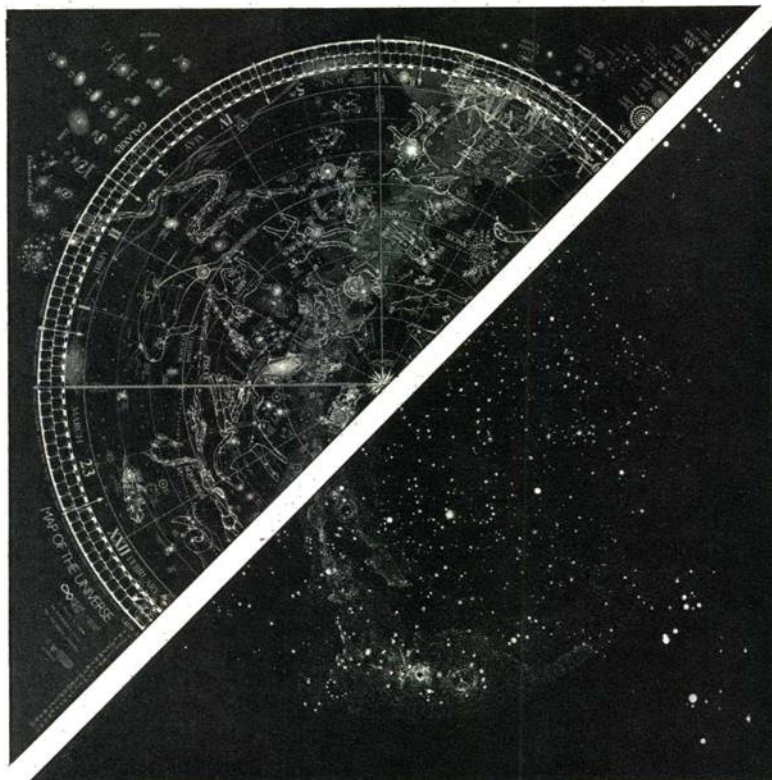
The X-ray source Aquila X-1 flares up like a nova at both X-ray and optical wavelengths roughly every twelve to sixteen months. At maximum, its X-ray intensity rivals that of the Crab Nebula and its visual magnitude jumps from +19 to +15. A typical flare lasts several weeks.

Now, using the X-ray satellite Hakucho, a team of Japanese astronomers has detected something new from Aquila X-1: X-ray bursts, sudden jumps in X-ray output which last only seconds. The scientists reported recently in *Astrophysical Journal Letters* that the satellite detected two such bursts as Aquila X-1 was in the declining stage of its last flare, back in May 1980.

We already know that Aquila X-1 has an optical counterpart: a yellow or orange main sequence star whose spectral type is between G7 and K3. From the

spectrum of these bursts, the Japanese astronomers determined a radius for the X-ray source of between three and seven kilometers — which is approximately the radius of a typical neutron star. This strongly suggests Aquila X-1 is a binary consisting of a normal star and a neutron star.

One theory explaining X-ray burst sources treats them as just that — binaries in which one component is a neutron star. Material flows from the normal star to the neutron star, and the very intense magnetic field of the neutron star holds it back. When the pressure becomes great enough, the material suddenly falls onto the neutron star's surface. Since the gravitational field of the neutron star is so great, the matter has a huge amount of gravitational potential energy. This is partially converted into heat,



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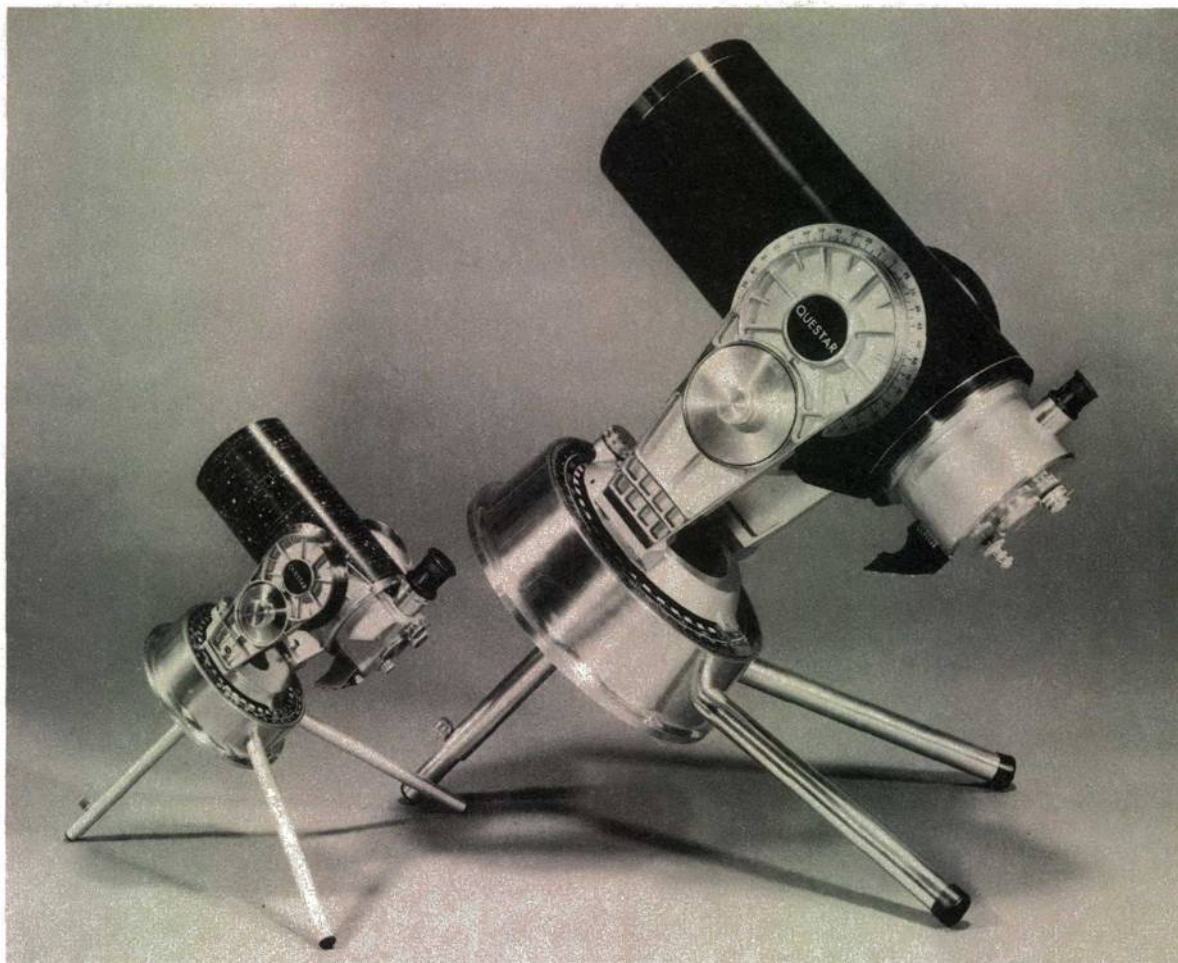
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Here the Questar Seven is shown as the overshadowing companion of its world-famous predecessor—twice as large and with double the performance: a portable observatory with the same superb mechanical and optical qualities as the Questar 3½, putting every refinement of the observatory telescope at your fingertips.

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The Seven also has the famous Questar system of built-in conveniences: low-power finder, high-power changes without changing eyepieces, star diagonal prism, synchronous electric drive, setting circles, worm-driven sidereal clock, and continuous 360° smooth slow motions. All are included in the price of the telescope, and included

too are the Questar totally safe solar filter and basic camera coupling set.

The Questar Seven is photovisual, of course, with four times the light grasp of the Questar 3½, and has the same easy way of adding a 35-mm. camera to the control box without disturbing the use of the eyepiece.

The remarkable Questar drive impresses everyone who uses it. Hubert Entrop, who takes beautiful deep-sky photographs (a number of which we have published here and in our recent issue of QUESTAR OBSERVATIONS), frequently comments on the quality of the drive. He has written us: "The motor drive on the Seven works very smoothly and quite precisely, even though the guiding is being done at twice the focal length of the 3½."

Another time, when sending us some pictures, he said, "The Seven base drive is so smooth that the shutter in the off-axis guider was not used even once for all four of these exposures." And again, "With the Seven there is never any problem in guiding; it no doubt has the best motor drive of any scope outside of observatory equipment."

These comments come from an observer who is using his equipment in all sorts of difficult terrain, on mountains, in the desert, and often under the most adverse weather conditions. In this regard he once wrote us that pictures he was sending to us were taken in winds gusting to 40 m.p.h. He concluded, "So these results are a tribute not only to the optics but also to the Questar design and drive mechanism."

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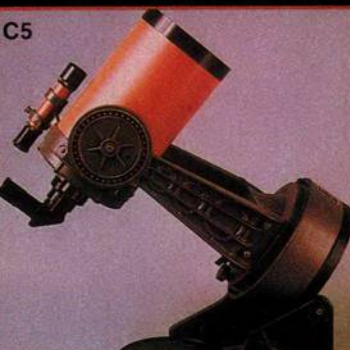
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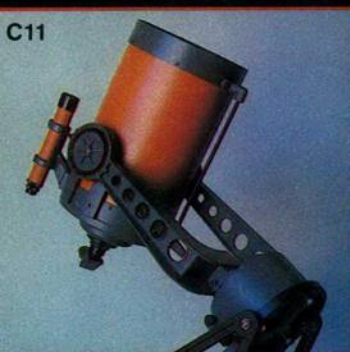
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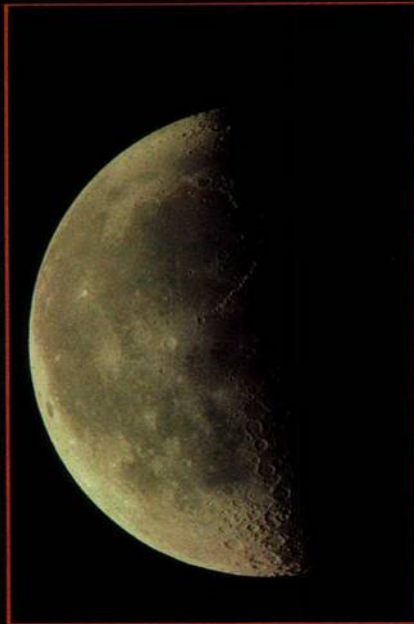
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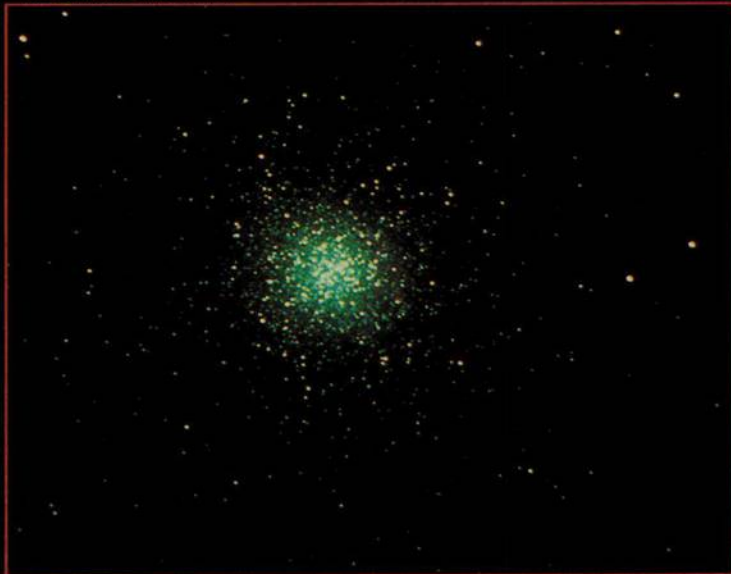
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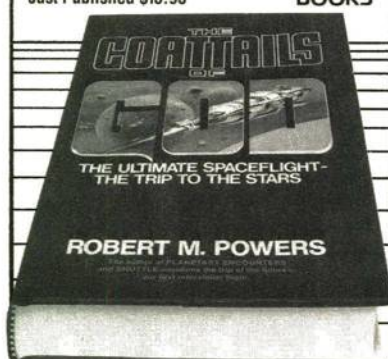
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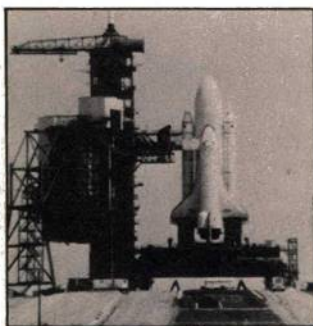
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ASTRONOMY REVIEWS

Astroscan 2001

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Barrington, NJ 08007

Nearly everyone who reads popular level science magazines will recognize the unique shape of the compact, colorful telescope futuristically dubbed Astroscan 2001. Edmund Scientific's widely advertised little red telescope is a short focal length rich-field Newtonian reflector that features closed optics for protection against dust and tinkering, an ultra-simple cast aluminum mount, and — considering its usefulness and value — a reasonable price tag.

Included with the telescope, mount, optical window cover, peep-sight finder, carrying strap, and literature is a 28mm modified Kellner eyepiece which delivers 16x and a generous 3° field of view. This is a substantial slice of sky — about six times the diameter of the Full Moon — for a small instrument.

In addition to bright lunar vistas, the Astroscan will show you Jupiter and the Galilean moons, the Andromeda Galaxy, colorful Albireo, the Great Nebula in Orion, sweeping Milky Way panoramas, the Pleiades, numerous stellar clusters, and other objects which are at their best in a wide-field perspective.

The Astroscan's images are bright

and sharp, but as with any instrument having a focal ratio of just over $f/4$, coma is noticeable at the edge of the field. This is not a significant drawback to an otherwise excellent optical system.

The focuser takes standard 1¼" outside diameter oculars and is a rubber-roller type. Although not sophisticated in design, it operates smoothly, without backlash or creep, and it will "crisp up" a stellar image as well as many high-priced helical or rack-and-pinion systems.

Though you can use eyepieces of any focal length you like on it — and thereby change the power of the scope — there is a practical limit of about 75x in most cases. While the telescope's images are good, they aren't so good that you can pour on the power without severely degrading the image. This isn't really a fault — since the Astroscan was not designed as a high-power instrument.

The coated and sealed optical window (to which the secondary mirror is attached) reduces thermal currents in the interior of the telescope to nearly zero; in this respect, the Astroscan has some of the advantages of a refractor. I have taken the instrument from a heated room to below freezing temperatures outside with negligible effects on star images and quality.

Extremely portable at eight pounds, and only 17" long, the Astroscan can be whisked outside, placed on a flat surface, loaded with an eyepiece, and

aimed at the stars in just a minute or two. On those evenings when your only viewing is through drifting holes in the cloud cover, the Astroscan quickly settles the question of whether it's worth lugging a scope outside and setting up.

Contrary to some advertising photographs, holding the lightweight telescope on your lap while viewing the heavens is not satisfactory. Instead, set up a sturdy photo-tripod outside and remove the little retainer screw that holds the Astroscan to its base. The hole for the retainer screw has standard ¼-20 threads and will screw down onto your tripod head. You can then adjust the height of the tripod to place the scope for convenient observing. But remember, if your tripod wiggles, the images in the telescope will dance whenever you touch it. If you don't have a tripod, set the scope on a park bench or another sturdy object.

In use, the round bottom of the telescope rests in its base, supported at three points on felt pads. It moves with a smooth, gliding action similar to that of a good ball-and-socket joint, but with enough friction so the telescope doesn't run away on you. You can swing the Astroscan around in any direction with just fingertip pressure, and it will stay where you aim it with no backlash.

Several accessories are available from Edmund: an erector lens system for terrestrial viewing, a rubber eyecup that fits over the eyepiece to

reduce stray light, a tote bag, and a camera adaptor. Other suppliers sell a solar filter that fits the Astroscan.

Storing the telescope is no problem. Unlike its bulky, large-aperture cousins, the Astroscan will easily find a home on a bookshelf, mantel, or in a corner of the closet.

Convenient, sturdy, and well constructed, the Astroscan 2001 is an exceptional and economical window on the the visible universe. *Gail O. Clark.*

New Earths

James Oberg

320 pages, hardcover, \$16.95

Stackpole Books (1981)

Imagine developing a breathable atmosphere on Mars or the Moon — or snatching a satellite from Saturn and hurtling it toward the inner solar system. Impossible as these tasks may seem to you now, by the time you've finished *New Earths*, the idea of terraforming or rebuilding whole worlds for human habitation or benefit may appear not only possible but quite reasonable.

Oberg is quick to point out that terraforming really isn't new — people have been renovating the landscape for centuries. The most obvious examples are in Holland, where the

Dutch have reclaimed great tracts of land from the North Sea. Despite this, Oberg notes that Earth's major terraforming projects still lie in the future, possibly taking the form of weather and climate control, or the diversion of rivers to desert areas.

New Earths deals extensively with terraforming other planets and creating new environments that would be "capable of supporting Earth-derived life, including people, without significant restrictions." Oberg lists three prime targets for extraplanetary terraforming missions: Mars, Venus, and the Moon.

Mars, which has enjoyed the special attentions of science fiction writers and scientists for decades, might be the easiest to terraform. The water needed to build a new martian atmosphere and oceans may be locked away in the ice caps and below the martian soil as permafrost.

Venus — hellishly hot — is likely to be much more difficult to terraform, though perhaps not impossible. The key to adapting Venus will be in finding ways to get rid of the excessive heat and reduce the mass of the venusian atmosphere.

And the Moon, Oberg feels, for all its barren appearance, may be fairly easy to terraform. It's also close to home.

Reworking the planets to an acceptable level of Earth-like conditions will require a variety of resources and tools. The volatiles — chiefly water — for making atmospheres and oceans may have to be imported in massive amounts from the asteroids or from jovian and saturnian moons if they cannot be found "locally." Even the atmospheres of Jupiter and Saturn could be scooped up and delivered bit by bit to a planet undergoing terraforming.

Engineers and scientists will have to develop new methods for moving great quantities of matter around the solar system in order to make terraforming a reality. Three systems appear to have potential: mass drivers — electromagnetic catapults that would use part of the body being moved as reaction mass; light sails, which tack slowly but inexpensively about under the pressure of sunlight; and various forms of nuclear propulsion.

Even celestial mechanics can be put to work. To help speed a saturnian moon on its way to the inner solar system, Oberg suggests a "reverse Jupiter swingby." Just as the Voyager spacecraft used Jupiter's gravity to accelerate toward Saturn, a saturnian moon could use Jupiter's gravity to speed its fall into the inner solar

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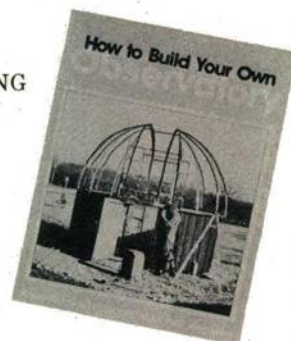
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system.

Looking at more specific methods, Oberg suggests using immense parasols, hundreds of miles across, to shade parts of Venus. In like fashion, the temperatures of Mars could be increased by using giant mirrors to augment the available sunlight.

Organisms such as algae, lichens, and methanogens could transform newly created atmospheres into something that humans can breathe. If these life forms prove inadequate, new and more efficient biological tools might be genetically engineered for the job.

But before any grand terraforming projects can be attempted, humankind needs a fairly complete knowledge of how Earth's biosphere works. Oberg discusses some of the important components of the biosphere — the atmosphere and oceans, for example — and how they interact to maintain life on this planet. Even seemingly minor items such as dust and electromagnetic flux may play a vital role in sustaining life. Without comprehensive knowledge of how a biosphere functions, attempts at planetary engineering will fail.

Many readers will probably ask "Why?" or "What right do we have to export our technology to the rest of the solar system?" At present, these

questions are academic. Oberg concludes that the decision to terraform or not will be the choice of future generations. Yet, with so much to be learned, it's impossible to forecast when or if the step will be taken, and what the deciding factors will be.

New Earths makes a good case that, given the proper resources,

technologies and knowledge, planetary engineering is possible. But Oberg does not blindly advocate terraforming. Instead, he urges further "investigation of the possibility of planetary engineering," and acknowledges that future generations will have to make the actual decisions. All we can do is outline the possibilities. *Robert Nichols.*

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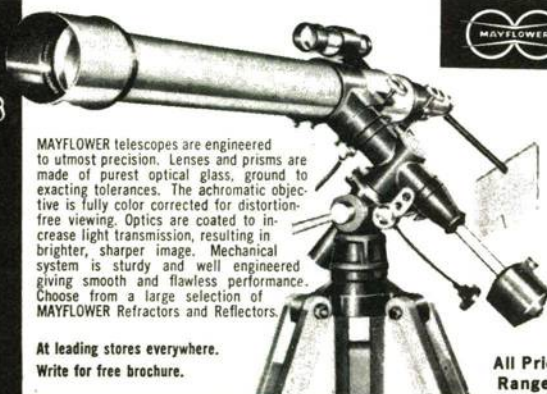
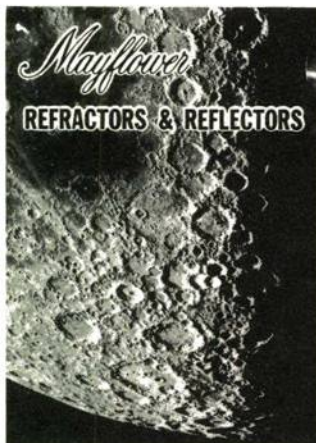
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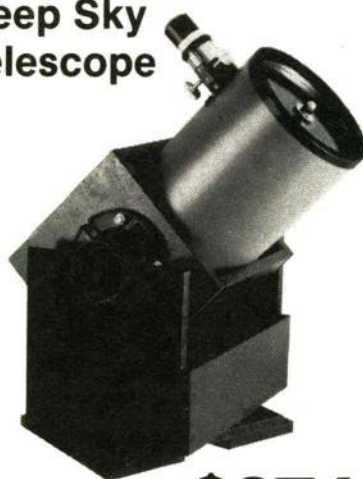
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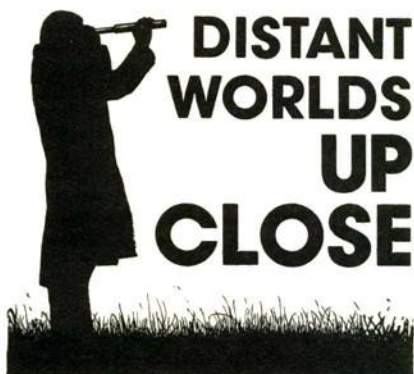


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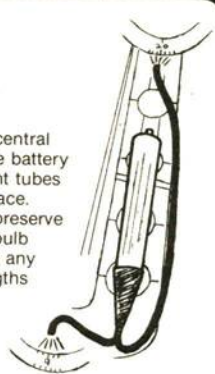
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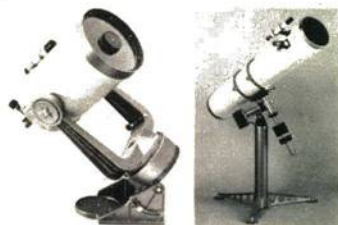
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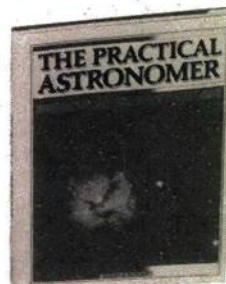
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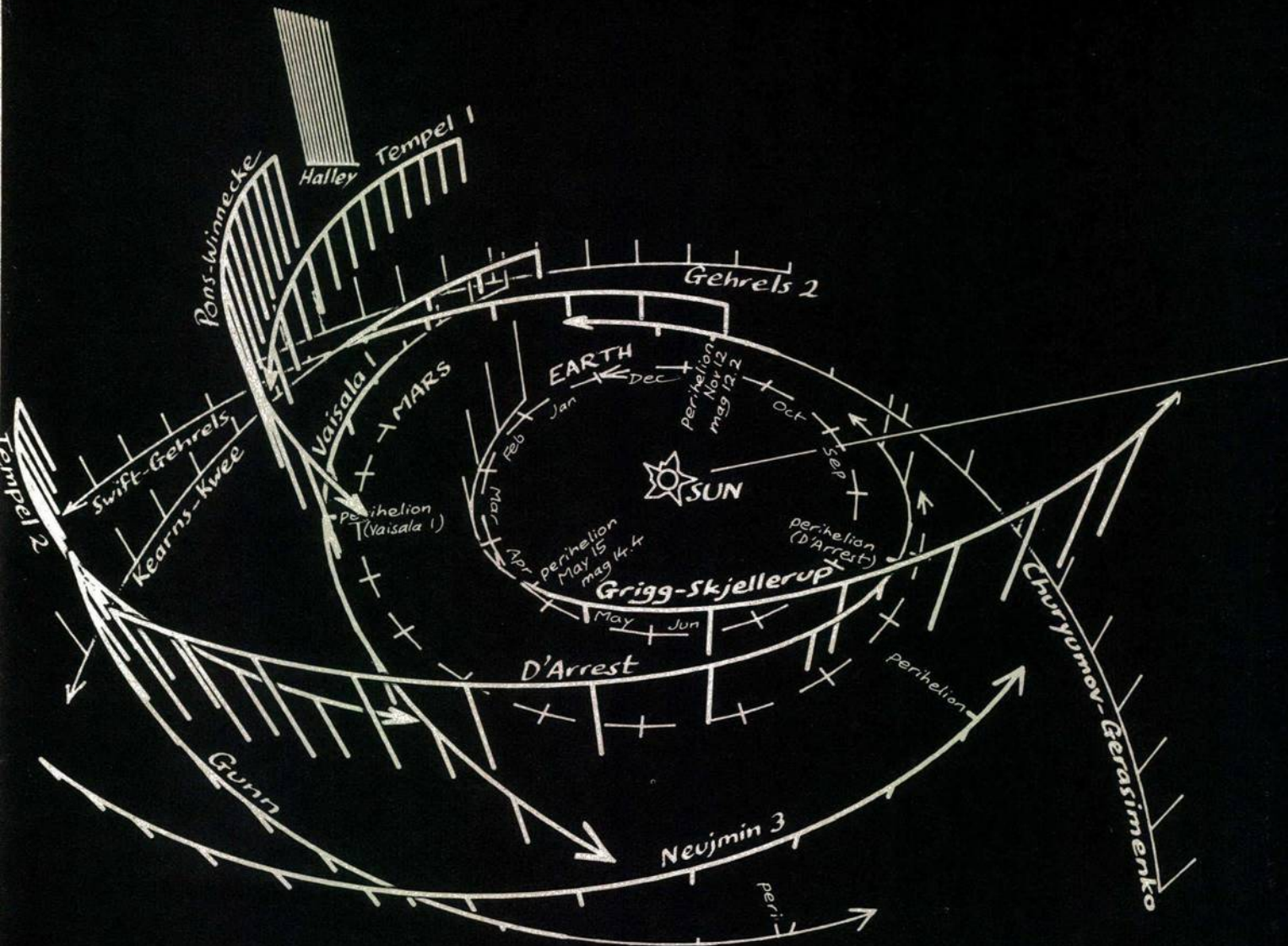
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the Search for Extrasolar Planets

by David Finley

Are we alone in the universe? Is the Sun's family unique? Or are there other planetary systems — cousins of our own — scattered among the stars?

Almost 400 years ago, the Italian philosopher Giordano Bruno wrote of "numberless Earths circling around their Suns, no worse and no less inhabited than this globe of ours." This closed the door on Bruno's scientific and philosophical career — the Catholic Church burned him at the stake for heresy — but it opened the door for many scientists after him. Today, the possibility that other solar systems, other worlds, and other forms of life exist in the universe has become widely accepted — although we have not yet found a single planet circling another star.

But this absence of proof may not remain much longer. Right now a small number of astronomers are assembling the instruments to begin a momentous search to answer this question. With the results, we ought to know — probably within 10 years — whether many of the nearby stars have giant Jupiter or Saturn-sized planets around them. And what's even more exciting, still better instruments will soon be sent into space, where, freed from atmospheric distortions, they will operate at maximum efficiency and perhaps detect smaller Earth-sized planets around nearby stars.

Dr. William Brunk of NASA says that while only about 25 people nationwide are involved, these include "the best instrumentalists in the business," adding that the creation of this new detecting apparatus is "almost an art."

Those involved understand the importance of their work. "If planets are found to be as abundant in the universe as some of us suspect, the impact on human philosophy may be greater than that of any other astronomical discovery of our time," says one. But another scientist asks: "Can you imagine the reaction that would ensue if we could prove today, without a doubt, that the Sun possesses the only planetary system in the universe?"

Obviously, the discovery of extrasolar planets would give new focus to the search for extraterrestrial intelligence, and, says Dr. David C. Black of NASA's Ames Research Center in California, "would form the basis of a space program for the next century."

Knowledge of another solar system would also help us learn about how planetary systems, including our own, originate. Scientists who study the planets work under the distinct handicap of having only one such system to observe — a problem unknown to those who study stars, galaxies, quasars, or even such arcana as potential black holes. A planetary scientist is like a biologist who is allowed to study only a single leaf of one plant species — from which he must extrapolate everything: origin, growth, and evolution.

The search to detect other planetary systems, according to a NASA report, "could provide a breakthrough in the understanding of such systems comparable to that afforded by the Hertzsprung-Russell diagram in the understanding of stellar evolution."

What, finally, has made this search possible?

It hasn't been due to any single dramatic breakthrough, but rather a steady advance in such varied technologies as computers and fiber optics. While some astronomers are hoping to devise a means of directly detecting reflected light from extrasolar planets — an extremely tough job technically — most are working on more indirect methods of finding planets.

One method is the "ancient" art of celestial mechanics — it can provide a good, although subtle, clue to a distant planet's existence. A planet and its star form a system in which both members orbit around a common center of mass. The location of this center of mass, or *barycenter*, depends on the relative masses of the objects and their distance from each other. Naturally it lies closer to the more massive object.

For example, a Sun-and-Jupiter system would have a barycenter just a little outside the surface of the Sun, so a distant observer might notice a cyclic wobble, or *perturbation*, in the Sun's motion as measured with reference to very distant stars. The perturbation would be due to the Sun's orbit around the system's barycenter. Astronomers seek to detect this wobble in the motion of other stars.

In practice, the problem is complicated by the fact that although perturbations of this type may appear large nearby, they diminish to minute proportions when viewed from typical interstellar distances. To return to our example, if we were to view this Sun-Jupiter system from some 30 light-years away, the perturbation in the Sun's proper motion would amount to only about 0.0005 second of arc. This perturbation is about five to ten times smaller than we can just barely detect today — let alone measure with any accuracy.

To gain an accuracy sufficient to detect extrasolar planets, astronomers are bringing new technology to the old science of astrometry, the determination of exact star positions.

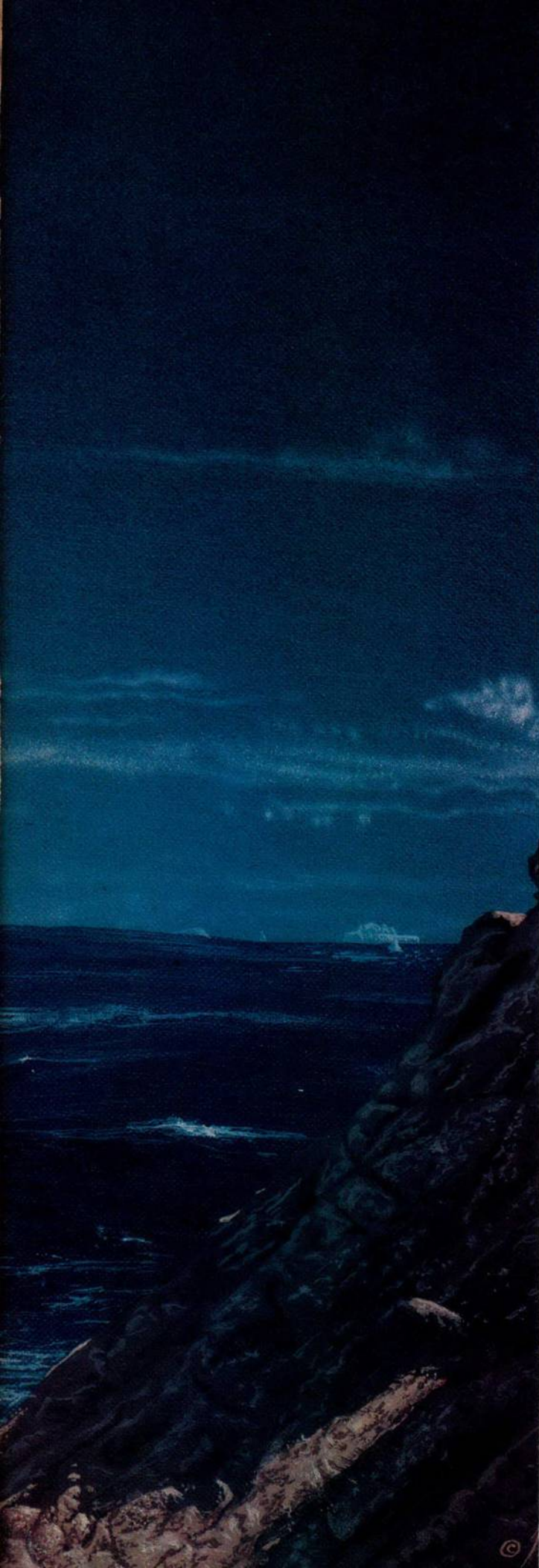
The first casualty has been the photographic plate, a mainstay of astronomical research since the late 1800s. Photographic emulsions fail to achieve the necessary positional accuracy because emulsions don't hold their physical dimensions stably enough. Moreover, even the most sensitive require long exposures that permit atmospheric seeing to fatten pinpoint stellar images into imprecise blobs.

Dr. George Gatewood of Allegheny Observatory began an observing program late this past summer with a new astrometric instrument that he calls a Multichannel Astrometric Photometer (MAP). This instrument, which replaces a photographic emulsion with a much more sensitive array of photoelectric detectors and analyzes the resulting data by computer, is expected to provide accuracy of about one milliarcsecond (0.001 second of arc).

Meteors streak over the landscape of a moon circling a planet in a hypothetical solar system. Painting by Michael Carroll.







The MAP, which uses Allegheny's 30-inch refractor, consists of about a dozen fiber optic bundles placed at the telescope's focal plane in positions where photographs have shown the images of selected stars will fall. The fiber optic bundles feed individual photometers. The MAP then sweeps a Ronchi grating of very thin lines, closely spaced (4 line pairs per millimeter) and precisely parallel, across the focal plane — alternately blocking and passing the light of the stars. The ruling lines and the spaces between them are equal in width and slightly narrower than the star image; as a result, they never block the star's light completely.

As the ruling passes over the star field, the output of the photoelectric detectors (connected to a computer) swings up and down in a regular fashion. Since the distance (in the telescope's focal plane) between two stars can be measured to the nearest whole number of ruling lines, the exact distance can be determined by adding to the whole number of ruling lines the difference in phase between the signal waves put out by the detectors for each of the two stars. This effectively takes position plotting out of the realm of mechanical measurement and puts it where electronics can measure it much more precisely.

Even more useful is the way the MAP operates with little regard to the differences in stellar brightness. Trying to measure on a photographic plate the distance between Sirius, say, and an 11th magnitude star nearby would be just about impossible. An exposure that recorded the 11th magnitude star would show Sirius as a gigantic, overexposed blob whose exact center was a matter of guesswork. The MAP records both stars equally well and can pinpoint the centers of each. In addition, the disturbing effects of atmospheric distortion can be minimized by averaging the results of many such observations.

Gatewood's observing program will concentrate on relatively nearby stars and seek out planets approximately the size of Jupiter. He estimates the program will take about 12 years — the orbital period of Jupiter. "We would like to see one full cycle," he says.

Ironically, Gatewood himself got into the field by showing that the supposed existence of one planetary system was probably due to observational and measurement error.

Astronomers from Sproul Observatory near Philadelphia began writing as early as 1943 that their comparisons of photographic plates taken over several decades showed perturbations that indicated possible planetary systems. Gatewood and his fellow astronomers attempted to confirm the Sproul data by using various telescopes, but they could not. Later, scientists saw that some of the observed perturbations in the Sproul plates happened at those times when the 24-inch Sproul refractor had been re-adjusted — which damned the results.

"Then, about four years ago, David Black of NASA called me up," Gatewood recalls. "He said I had a reputation for wiping out solar systems. He wondered if I could start finding planets instead. I had really never thought about going to look for them!"

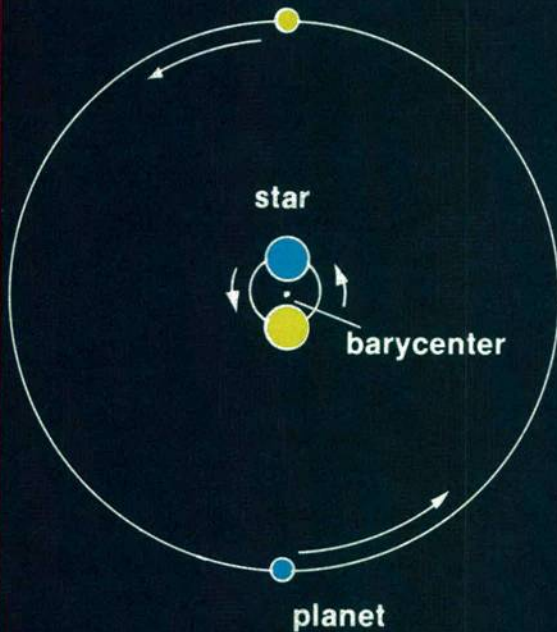
Gatewood's MAP — besides immediately offering improved astrometric accuracy — promises to improve even more with time. He says, "Each measurement of the distance between two stars yields the relative positions of the lines on the grating with which the measurements were made." Thus, after a few years of use, the relative position of each ruling line will be known to a precision limited only by the stability of the glass that is used.

Also, the MAP can eventually reveal the errors in the optical system of the telescope with which it is used. By letting a precisely-measured star field drift around the telescope's field of view while following it with the detector

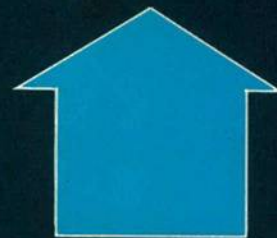
New techniques will allow astronomers to detect Jupiter-sized planets orbiting distant stars. Painting by Michael Carroll.

detecting extrasolar planets

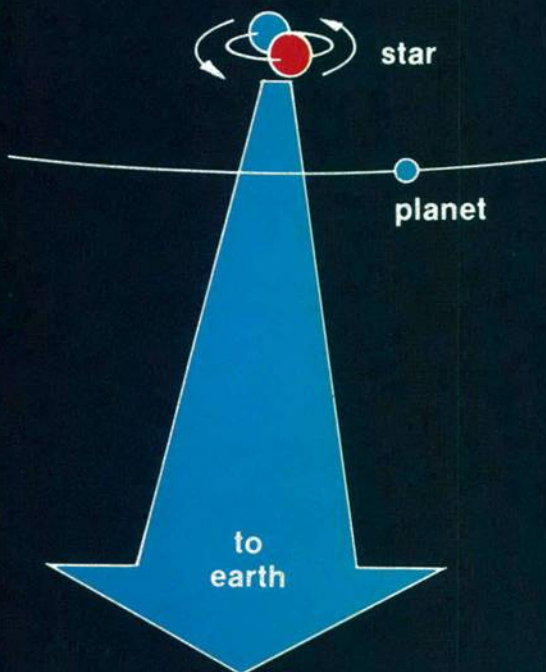
as star and planet orbit the system's barycenter. . .



. . . we measure tiny perturbations in the star's path.



orbital motion also makes minute



doppler shifts in the star's spectrum.



blue shift when approaching



no shift when moving across the line of sight



red shift when receding

Where is the center of Sirius in this photo? Electronic measurements now pinpoint star positions. Lick Observatory photo.

array, any distortions in the optical system will show up as changes in the stars' apparent positions. With this possibility for correcting optical errors, Gatewood believes that there is a very real probability that existing astrometric telescopes can achieve precisions far beyond the expectations of their designers.

Astrometry, though, will reach its full potential only in space, where the images arrive at the telescope undistorted by Earth's atmosphere. An astrometric telescope in space could detect stellar perturbations of one millionth of an arcsecond, or approximately the angle produced by the thickness of a piece of paper in California — as viewed from Florida. "With that, you begin to approach an accuracy sufficient to detect the incredibly small perturbations of Earth-like planets," Black says, estimating that \$100 million could build and launch such an instrument.

But astrometry is not the only search method benefitting from new techniques. The hunt for extrasolar planets is also helping to produce a new generation of spectroscopic equipment.

Perturbations in a star's motion can also be detected by changes in the star's radial velocity — that part of its motion which is directly toward or away from us. Luckily, the accuracy of such observations does not depend very much on how close the system is. Astronomers have been observing and measuring stellar radial velocities by their Doppler shifts for years, typically to an accuracy of about one kilometer per second. The best of present-day equipment can determine a radial velocity to within about 50 meters per second.

Looking again at our hypothetical Sun-Jupiter system, the Sun's radial velocity would show a difference of 10 to 13 meters per second due to its orbit around the barycenter. Therefore, spectrographs with this degree of accuracy should be able to reveal a Jupiter-sized planet. Equipment now under development promises such precise measurement.

Spectroscopy traditionally has been carried out with a prism or diffraction grating coupled with a telescope. This combination breaks a star's light into a spectrum, which is then recorded on film. Atmospheric turbulence and the instability of the instruments combine to limit the accuracy of this method by making the image of the spectrum jump around slightly, thus blurring the emission and absorption lines which serve as bench marks for measuring the radial velocity.

A solution to this problem lies in new fiber optics that are both larger and more efficient than their predecessors. Some of these new fibers can transmit light for 30 feet or more and lose only 5% of what they picked up — more transparent than most windows (which lose about 15%). The biggest advantage of the new fibers, though, is that they are fatter than the old ones: fat enough that, when a star's image lies centered on the end of one, atmospheric distortions can dance the star's image around within normal limits and all the light will still go down the fiber.

This means that at the other end the light output remains steady and stable. The effect is like a garden hose with a big funnel in one end. You can dump water into the funnel however sloppily you like and it will still emerge from the other end of the hose in a steady stream.

In the case of fiber optics, the result is a stable stream of light that can produce a very sharp spectral image. (Remember, spectroscopic astronomers are not interested in the star's image, only in piping a steady supply of its light into a spectrograph.) In the newest instruments, photoelectric detectors have replaced plate emulsions to increase accuracy even more. The extended usable length of the newer fiber optics also allows the actual spectrometer



to sit undisturbed on the observatory floor. By not riding on the telescope, the instrument stays free of flexure and attitude distortions that add internal errors.

The radial velocity technique offers astronomers an immediate advantage: no instrument has to be sent into space to realize its full potential. After all, the atmosphere does not impede the spectral information necessary for radial velocity measurements; it merely constricts the range of wavelengths — from ultraviolet to infrared — over which astronomers can search out the tiny shifts in the positions of the spectral lines that would betray the presence of a planetary system.

As a bonus in this search, the astrometric and radial velocity techniques complement each other. The astrometric method works best when the plane of the planet's orbit is perpendicular to us; the star's image then describes a circle, a corkscrew, or a wavy line on the sky. The radial-velocity method works best when the planet's orbit is edge-on; we then see rhythmic changes in its radial velocity. By combining the two methods we can minimize the garbling effects that result from the random orientation in space which planetary systems will undoubtedly have.

While experimental researchers perfect their instruments, there is other work being done. Some of it centers around how to interpret the data the new instruments will provide. One study focuses on the Sun to find out if rapidly rising and falling currents of gas in stars could bias the radial velocity measurements.

"We have to do our homework," emphasizes Brunk, the NASA scientist. Black adds "We're entering a whole new regime here. Strange things you could ignore before now will bite you if you're not careful!" For example, Gatewood points out that, with the accuracy achievable in orbiting astrometric instruments, even starspots could create errors by causing small but perceptible shifts in the center of the star's image.

And so, mixing caution with great anticipation, the search has begun. Black, who is in charge of allocating about \$200,000 a year in NASA money to researchers in this field, says, "Our ability to answer the question of whether other stars have planetary systems is limited only by our willingness to invest time, thought, and money."

The technology has reached the point that in a mere ten years we will know, for 100 or 200 of the nearest stars, whether or not they have planets down to the size of Jupiter. At the very least, we are going to know if any other solar systems exist nearby.

That, says Brunk, "is a very exciting prospect."

David Finley is editor of the Science/Medicine section of the Miami Herald. He also freelances articles on astronomy and physics.

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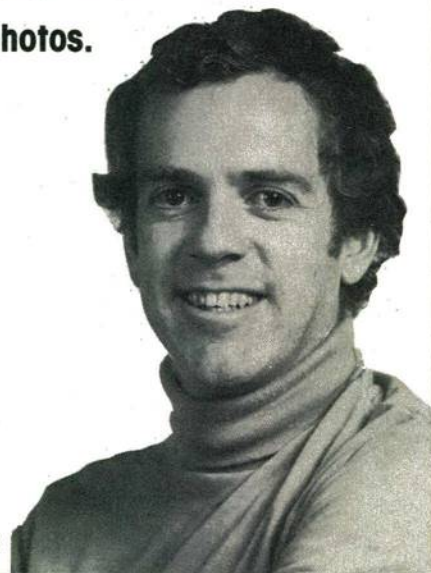
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"An eyepiece is an eyepiece — why spend any more than you have to on them?" said a friend of mine when I mentioned I had just purchased a set of Tele-Vue eyepieces. Certainly at \$55 each, the price is enough to make anyone stop and think twice. But I am satisfied because the Tele-Vue Plössl is the sharpest I've ever used.

For years I've gotten along with a pretty ratty set of eyepieces, some that I bought 20 years ago, some that came with various telescopes, and a big Erfle I bought a few years ago. I've looked at, and been tempted by, newer ones, but whenever I've compared them at ATM meetings, I haven't seen any that gave sharper images than those I already own.

The Plössls arrived looking beautiful. Nothing was loose; nothing rattled or shook. They were extremely clean and dust-free. For a quick check, I tried all four in my Astroscan — then I knew I had something good! Even with the f/4.5 optical system of the Astroscan, the images were crisp and sharp nearly to the edges of the field. When I focused, the image seemed to "snap" at the moment of best focus instead of mushing through focus as do many eyepieces used on a fast optical system.

I frequently use the Astroscan for projecting the solar image. My trusty old 28mm Kellner eyepiece does a terrible job — the image is mushy and has color fringes. The 28mm RKE is a vast improvement — but it still is a bit soft through focus and some detail is lost. The 26mm Plössl does a superb job — tiny low-contrast details in sunspot penumbrae stand out sharply.

Used with my 12" f/7 telescope, the Plössls deliver crisp images of the planets. I have the distinct impression that the eyepiece adds no optical errors to the image I'm viewing, and that I am seeing everything the mirror can deliver. This is an impression I've never had with any other eyepiece.

Tele-Vue's Plössls also look handsome. They are quite heavy, feel solid, and possess details of fine workmanship. Their shape fits my eye quite comfortably. Although the 26mm can be used with glasses on, I must remove mine to use the others. Without glasses on, I must refocus slightly when I switch from one eyepiece to another. One slight note of caution: the barrels of these eyepieces are exactly 1.250" in diameter. Since one focuser I own is undersize by several thousandths of an inch, the Plössls do not fit it properly. If you buy these eyepieces, you may also have to upgrade your focuser.

Are these eyepieces worth their price? If you are using a slow optical system, most eyepieces will give you a satisfactory image. With fast optics, however, I haven't seen anything to match them.

Richard Berry.



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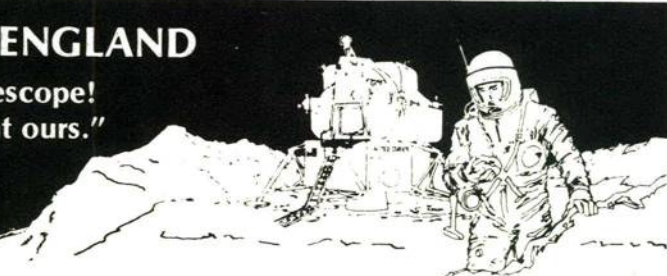
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the backyard astronomer

camelopardalis

Sometimes it seems like nature is out to get you: with the single exception of Venus — a grand sight in the western evening sky — all the best sights this month are visible in the hours between midnight and dawn. If you bundle up and brave the cold, you'll see three bright planets — Mars, Saturn, and Jupiter — as well as two meteor showers.

Mercury

Passing through superior conjunction on the same day as it reaches orbital aphelion (the 10th), Mercury will remain out of sight for most of December. You may catch sight of it very low in the southwest just after sunset during the last few days of the month, but only if your local conditions — weather, horizon clutter — are favorable.

Venus

An "evening star" for the holiday season, Venus is magnificent this month. At its highest elevation above the horizon in mid-December, the planet also reaches greatest brilliance on the 16th, -4.4 magnitude (see *Eye on the Sky*, page 34). As you can tell by comparing the drawing of Venus' disk for this month (at right) with those of the last few, its increased size is strikingly apparent.

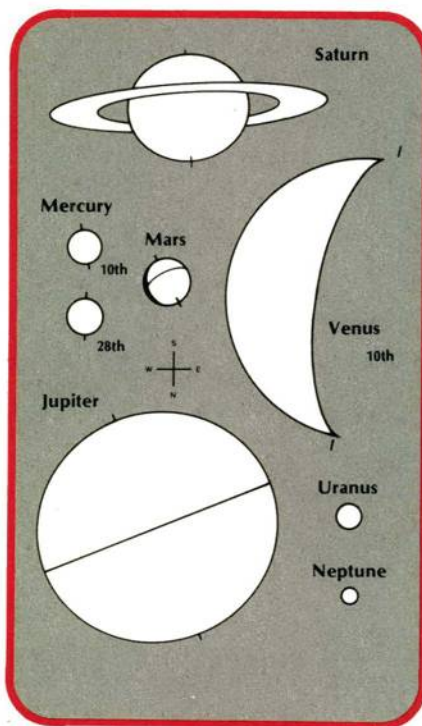
A number of observers report seeing the phases of Venus in binoculars when the planet appears large. What can you see? Try to look during twilight before the contrast between the blazing planet and the darker sky becomes too pronounced. If you brace your binoculars on a photo-tripod or the side of a building, you'll have a better chance. Of course, a glance through a telescope reveals the crescent shape immediately and makes it easy to follow the rapidly-changing phases.

At 3:12 UT on the 11th, Venus will pass about a minute of arc north of the 6.0 magnitude star 4 Capricorni. At the time of closest approach, Venus will

have set for all observers except those on the west coast. However, even as seen from the east coast, the star and planet pair will be quite close together (and worth a look) before they disappear below the southwestern horizon.

Earth

The Sun reaches celestial longitude



270° and, simultaneously, the "low point" on the ecliptic at 22:51 UT on December 21: this marks the northern hemisphere's winter solstice. Later will come the coldest weather, moderated and delayed a month or two by the thermal inertia of our planet's oceans and atmosphere.

Mars

Moving steadily eastward through Leo into Virgo, Mars will be high in the southern sky in the hour before

sunrise. It's a pity that, with such a favorable position, the planet's disk is only 6" to 7" of arc in diameter.

Around Christmas, Mars will be 90° to the west of the Sun in the sky — a point known as quadrature. At this time, the planet's disk will be 90% lit and will appear distinctly gibbous with moderate to high power. As with Venus, you may notice its phase effect better in twilight.

Asteroids

1 Ceres (magnitude 8.4) is in eastern Virgo and passes just under a degree (57') to the north of 4.1 magnitude Iota (ι) early on the 17th. About a week later, it will pass between Iota and its slightly brighter companion lying to the east, Mu (μ). Its positions:

10th: 14h 04m 24s, -4° 05.7'

20th: 14h 19m 25s, -5° 18.8'

Ceres rises about 3:30 a.m. local time on the 15th.

2 Pallas (8.6) is also in Virgo, but toward the west near Spica. Its positions:

10th: 12h 22m 51s, -8° 49.3'

20th: 12h 37m 39s, -8° 47.9'

Pallas rises around 2:30 a.m. local time at mid-month.

3 Juno and 4 Vesta are still very close to the Sun — both rise after morning twilight has started to brighten the sky.

15 Eunomia (8.8) is retrograding in central Auriga. From the 3rd of the month — when it passes between the open star clusters M-36 and M-38 — until around the 22nd, it will be transiting the star clutter of the Milky Way, affording interesting views to those who can find and follow it. Its positions:

The leafless trees of winter reach their spectral fingers toward Orion rising behind them — a familiar sight in the eastern sky on December evenings. To take this photograph — December's "Best Astro-Photo" award winner — Fred Hafell used a 5-minute exposure on 200 ASA slide film with an 80mm lens set at f/4.



Left: Tim Shelton set up his camera near Bratsk, Siberia to take this photo of the July 31 solar eclipse that shows prominences and the innermost corona. This page: A 10th magnitude spiral galaxy in Leo, NGC-2903 is a softly glowing whirlpool of stars trailing many arms and dust lanes. Photo by Martin Germano.

10th: 5h 23m 43s, +34° 32.5'

20th: 5h 12m 31s, +33° 21.9'

Eunomia transits the meridian about 11:30 p.m. local time on the 15th.

Jupiter

With Jupiter rising about 4 a.m. local time in the middle of December, you'll have a little over an hour and a half to observe it before morning twilight begins. Astronomically, twilight begins or ends when the center of the Sun's disk is 18° below the horizon.

Take your telescope outside and set the mounting on firm ground. Align it if it's an equatorial. A few minutes spent here will make your actual looking much easier and more enjoyable. Aim the telescope at Jupiter, using the finder scope or sighting along the tube. Put your lowest power eyepiece in the focuser — 15x to 45x is plenty to start with — and take a look.

Notice the distinctly oval shape of Jupiter. The planet is largely gaseous and spinning rapidly (a jovian day lasts 9 hours and 50 minutes); thus centrifugal force bellies it out at the equator and pulls it in at the poles. Across the disk, you'll see one or two grey stripes that run parallel to the equator: these are the two equatorial bands. Jupiter has a great many bands, belts, and zones — though seeing them takes practice, because they have low contrast and subtle coloration. Look carefully, perhaps with slightly higher powers (75x to 150x) — what can you see?

The next most obvious features in the jovian system are some little dots (two, three, or four) to one or both sides of the planet, strung out roughly in line with the jovian equator. These are the famous Galilean moons, discovered in 1610. If you watch day by day, you'll see their positions continually change. The innermost and fastest-moving is Io, which takes 1 day 18 hours to circle Jupiter; next out from it is Europa (3 days 13 hours). Then come Ganymede (7 days 4 hours) and Callisto (16 days 17 hours).

The movements of these little worlds mimic those of the planets around the Sun. Back and forth they go in their circles around Jupiter. Occasionally, one or more will cross over Jupiter's disk, heralded by a dark spot of shadow — so keep a sharp lookout.

Saturn

Saturn is somewhat to the west of Jupiter and rises about an hour before it — giving you a longer look.

But Saturn-watching differs from Jupiter-watching in two important ways. To begin with, although the two gas giants are approximately the same size, Saturn lies about twice as far away so its apparent diameter is only half that of Jupiter. Secondly, Saturn's "belt activity" is much less and its corresponding coloration (bands and zones) is much weaker. It takes practice to discern details on Saturn's ball.

Of course, since Saturn has those fascinating rings, you may not care very much about its belts. Currently, the rings are tipped about 12° to our line of sight and we are looking down on their northern side. For most of the decade, they will be slowly increasing their apparent tilt until they reach their maximum of about 27° in 1987.

Saturn has one large, easy-to-see moon — smog-shrouded Titan — which circles the planet every 15 days 23 hours. A host of others can be seen with the aid of a large telescope — or an on-the-spot spacecraft!

Uranus

Uranus is another of the Sun's four gas-giant planets. But though it is large, it orbits so far from us that we see only a dim, 6th magnitude dot of light some 3.5" seconds of arc across.

During December, Uranus will be low in the eastern sky, emerging from

but the Moon, between Full and Last Quarter, will brighten the sky and wash out all but the brightest meteors.

The Ursids fare better: peak activity is in the early morning hours of the 22nd, and the Moon then will have swept far enough around toward New not to interfere.

The "radiant" — apparent point of origin — for the Ursids is near Beta (β) Ursae Minoris in the Little Dipper. Ursids arrive at best with a rate of about one every five minutes; they are fast and pretty bright.

Bundle up and good luck!

close-up on camelopardalis

For some, thoughts of December evenings bring to mind sitting by a warm fire while fierce winds howl outside. For the dedicated observer, though, the thoughts go one step further. Those winds, cold as they may be, blow away clouds and leave the sky clear and crisp. It's on these special nights that faint wonders stand out boldly in the eyepiece, and stars seem bright enough to drown out even the corner street light. With skies like this, it's worth it to forsake home and hearth and haul your scope out into the cold — even if your friends and



the solar glare after conjunction with the Sun on November 22. It's faintly visible now among the background stars of western Scorpius, but you'll see it more easily if you wait another month.

Neptune

At conjunction with the Sun on December 16, Neptune will be out of sight until early in the new year.

Meteors

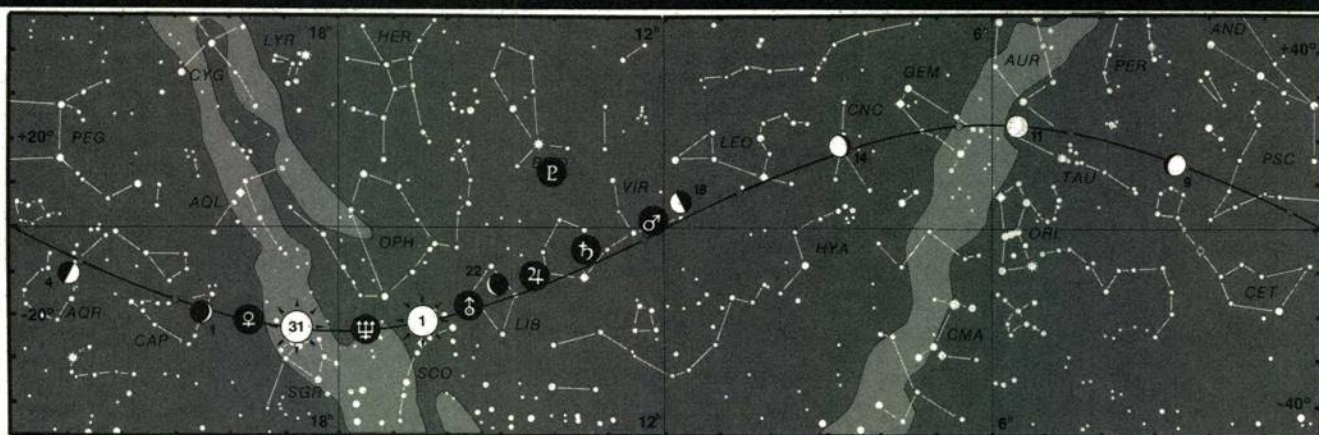
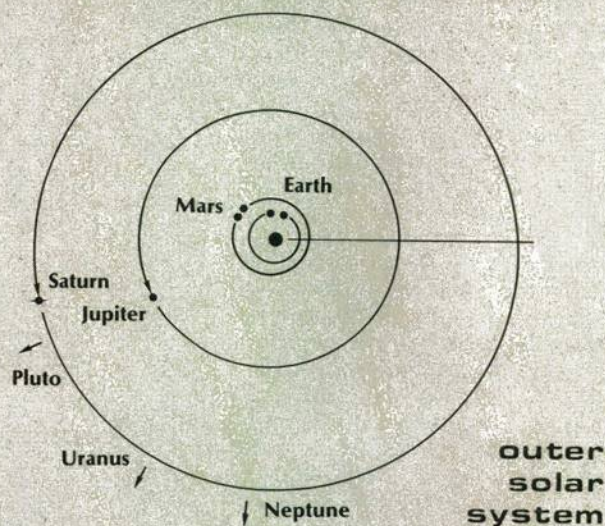
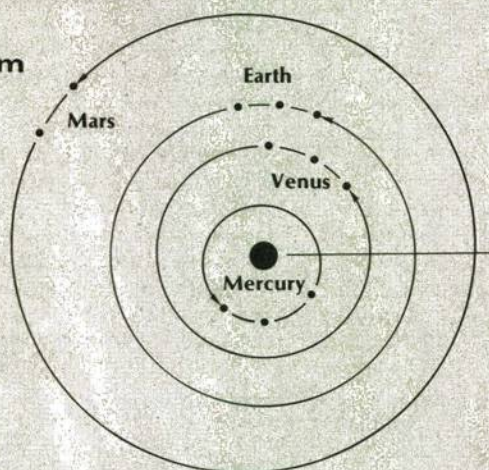
December has two annually recurring meteor showers — the Geminid and the Ursid.

The Geminids appear to come — as their name hints — from a region of sky in Gemini, near the star Castor. At peak activity they usually provide about one meteor per minute and are fairly bright. This year's peak comes in the early morning hours of the 14th,

family think you've lost your mind.

Astronomers can't be choosy about the weather. If the night is clear, and the seeing rated at 10 on a scale of 10, no amount of imagined frostbite can deter our observing efforts. Reward yourself, and bundle up appropriately, because nights like this only come a few times a year. Chances are you won't feel much of the cold — only the thrill of the stars. (See "Keeping Warm While Stargazing," ASTRONOMY, December 1980.)

While aligning on Polaris, take a look around. You'll see Orion over in the southeast accompanied by his cast of mythical figures. To your left is the winter Milky Way of Cassiopeia and Perseus, flanked by Auriga and Gemini. Dead ahead is the apparent void of the North Celestial Pole. There

inner
solar
system

	Date	Mag.	Angular Size	% Illum.	Distance (AU)		Longitude:		R.A. (1981.9)	Dec
					from: Earth	from: Sun	Heliocentric	Ecliptic		
Sun	1	-26.8	32.5'	—	0.99	—	—	248°43.0'	16h 27.9m	-21°45.3'
	15	-26.8	32.6'	—	0.98	—	—	262°56.0'	17h 29.2m	-23°15.1'
	31	-26.8	32.6'	—	0.98	—	—	279°13.9'	18h 40.1m	-23°07.2'
Mercury ♀	1	-0.7	4.7"	99%	1.43	0.46	231°44.3'	242°55.4'	16h 05.2m	-20°57.9'
	15	-0.8	4.6"	100%	1.44	0.46	270°36.5'	264°56.6'	17h 39.6m	-24°52.7'
	31	-0.7	5.1"	93%	1.32	0.41	320°23.1'	290°28.9'	19h 31.9m	-23°57.3'
Venus ♀	10	-4.4	37.1"	32%	0.45	0.72	52°33.1'	300°10.5'	20h 13.9m	-22°08.0'
	31	-4.3	52.7"	12%	0.32	0.72	86°21.5'	308°16.4'	20h 43.9m	-16°47.6'
Mars ♂	15	+1.2	6.4"	91%	1.46	1.66	143°28.7'	179°03.0'	12h 01.6m	+2°07.3'
Jupiter ♃	15	-1.3	32.6"	100%	6.04	5.45	205°26.5'	212°53.2'	14h 06.0m	-11°33.5'
Saturn ♄	15	+1.0	16.6"	100%	10.05	9.63	195°08.8'	199°53.6'	13h 18.7m	-5°45.9'
Uranus ♅	15	+6.0	3.5"	100%	19.77	18.85	240°40.3'	241°17.1'	15h 58.7m	-20°20.7'
Neptune ♆	15	+7.8	2.3"	100%	31.26	30.27	264°34.5'	264°05.3'	17h 36.3m	-22°04.3'
Pluto ♇	15	+14.0	—	100%	30.50	30.00	204°41.7'	205°50.5'	14h 01.8m	+5°30.9'

moon data

First Quarter December 4 at 16:22
 Full Moon December 11 at 8:41
 Last Quarter December 18 at 5:47
 New Moon December 26 at 10:10
 First Quarter January 3 at 4:45
 Full Moon January 9 at 19:53
 Perigee: December 11 at 0h... 356,809km
 Apogee: December 23 at 23h... 406,376km

universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times in The Backyard Astronomer are UT unless otherwise noted. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska and Hawaii, 10. For example, if an event is to happen at 03:00 hours UT on January 2, then EST for the event is 10 p.m., January 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m., March 4.



Above: A 16mm fisheye lens can record a lot of sky — and aurorae. The Big Dipper rises at right, while Cassiopeia descends on the left. Photo by Bill Smith and Dan Marcus. Overleaf: 225 kilometer diameter Clavius (top center) and 85 km Tycho (bottom center) dominate this region of the Moon's southern highlands. Straddling a line between them are the "twin" 150 km craters of Maginus (left) and Longomontanus (right). Photo by Daniel Messina who used a 10-inch Schmidt-Cassegrain scope with a 2-second exposure at f/64 and 64 ASA slide film.

are many worthwhile objects to search out in this seemingly empty section of the heavens. Flip open your star chart and study it under the red glow of your flashlight. Notice the small circles and other symbols signifying invisible deep-sky objects, and then a vague constellation called **Camelopardalis**.

"Camelopardalis?" you mutter under your breath. "I thought that was a southern constellation." Well, it isn't. Although it occupies the area between Cassiopeia, Perseus, Auriga, Lynx, Ursa Major, Draco, and Ursa Minor, Camelopardalis is not often included in most observing programs — even though there are some fine sights to be seen here.

Only two of the stars that make up Camelopardalis are easily visible, and the remaining five are nearly 5th

satellites of jupiter

10:00 ut

1	430	• • ●	16	43012	• • ● •
2	4302	• ● •	17	403	• • ●
3	2403	• • •	18	4203	• • • •
4	21043	• • • •	19	40123	• • • •
5	01234	• • • •	20	14032	• • • •
6	1024	• • • •	21	32014	• • • •
7	32014	• • • •	22	31204	• • • •
8	3104	• • • •	23	30124	• • • •
9	3024	• • • •	24	04	• • • •
10	2034	• • • •	25	2034	• • • •
11	21043	• • • •	26	01234	• • • •
12	0123	• • • •	27	10324	• • • •
13	4102	• • • •	28	32014	• • • •
14	43201	• • • •	29	31240	• • • •
15	4310	• • • •	30	43012	• • • •
			31	4102	• • • •

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)





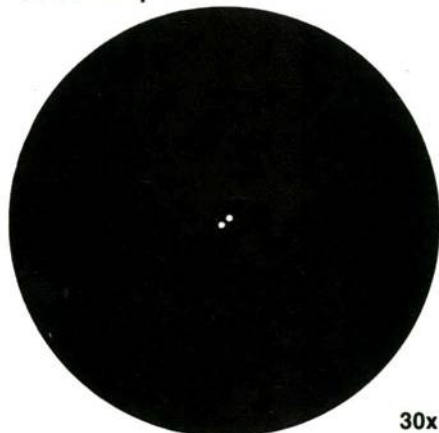
magnitude. Lacking the guidance of bright stars, you can locate Camelopardalis by looking in the area between Auriga and Polaris. Believe it or not, it's there — but you'll have to look on a dark night to see the figure.

Robert Burnham Jr. lists more than 100 double or multiple stars in the area as well as 24 clusters or nebulae — more than enough objects to keep you occupied on a long winter night.

Alpha, shining at magnitude 4.4, is an extremely bright star intrinsically and only appears dim because it lies 3300 light-years or 1000 parsecs away. If it were only 10 parsecs away, it would shine at a glaring -6.3 — six times brighter than Venus this month. **Beta** is also a highly luminous star and a G2 supergiant. To the eye it shines at 4.2, but again, if it were only 10 parsecs distant it would be a -5.2 magnitude object.

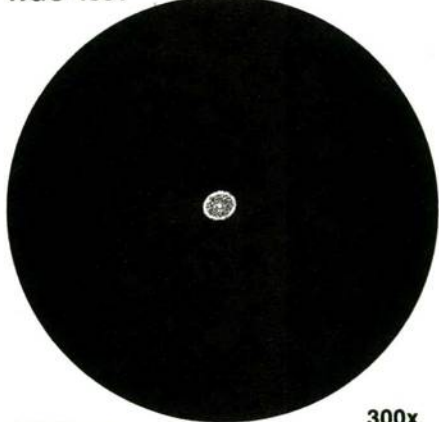
Aiming your telescope two degrees north and slightly west of Alpha will center the variable star **ST Camelopardalis** in your eyepiece. Its range fluctuates from 7.0 to 8.4 and it is a spectral class N5 with no particular period of variation. Another N5 type star, located three degrees due west of the open cluster NGC-1502, is **U Camelopardalis**. Both stars are easily seen in small scopes and appear as deep red jewels of varying intensity.

32 Camelopardalis



30x

NGC-1501



300x

J. Mullaney

An additional strange star that approaches the threshold of small telescopes is **Z Camelopardalis**, an eruptive variable that can differ in brightness as much as five magnitudes. Discovered in 1904, Burnham labels it a "dwarf nova" since it shows constant, small-scale eruptions at intervals of two to three weeks. It normally rises to maximum in two days, but also exhibits periods of extremely erratic behavior. Keep a careful watch on this one and you may be surprised.

Camelopardalis' best double star can be found by drawing a line between Mizar and Polaris. **32 Camelopardalis** will be seven degrees from the end of that line. Glimmering at magnitude 4.8, it is the only bright object in the area. The components are almost equally bright at 5.3 and 5.8. They are separated by 22 seconds of arc and are a magnificent sight in small refractors as well as larger instruments. Some observers liken its colors to Albireo in Cygnus, but suggest that they are not as bright. The main star seems yellow and the companion has sometimes been called blue or lilac. Most observers agree that the color contrast is not very noticeable and is more a factor of observing skill. Both stars are spectral class A and lie at a distance of 300 light-years.

In addition to the fine double stars in the area, quite a few galaxies are visible in Camelopardalis. This is because we are looking away from the center of the Milky Way and out into intergalactic space.

One of the nearest of all spiral galaxies beyond the Local Group is **NGC-2403**, situated between Ursa Major and Camelopardalis. Sweep for it one degree above 51 Camelopardalis using low power. Often it can be glimpsed in binoculars as a large hazy spot. Magnitude estimates vary, but it seems to be about 8.8. In large telescopes, dark lines suggest spiral structure with dust lanes. Long-exposure photographs show it as similar to M-33 in Triangulum. The galaxy's distance from Earth is similar to that of M-81 and M-82 in Ursa Major, and Burnham suggests that it may be an outlying member of that group. The distance to NGC-2403 has been calculated as eight million light-years and it measures 37,000 light-years across. According to Alan Sandage, NGC-2403 was the first galaxy beyond the Local Group in which Cepheid variables were discovered. Many large hydrogen emission nebulae have been identified in it and this suggests that stellar formation is still an ongoing process.

Let's move back to Beta and then sweep due west for a faint naked-eye trapezoid of stars. Contained within this grouping is the dim planetary

nebula **NGC-1501**. It's out of the range of small telescopes, and you'll have to do some scanning with a moderate sized instrument to find it.

Although NGC-1501 can be glimpsed in a four-inch scope, it is a 10th magnitude object measuring only 56 by 48 seconds of arc. It is similar to the Owl or Eskimo Nebula, is oval shaped, and contains a 13th magnitude central star. It usually takes at least a six-inch scope to reveal its oval nature, and in an eight-inch the nucleus becomes more apparent. Long-exposure photographs reveal some mottled internal structure with bright and dark areas inside the disk. NGC-1501 is more than 14,000 light-years distant.

Now nudge your tube slightly to the north. One-and-a-half degrees in that direction lies **NGC-1502** — an open cluster that will please those with small telescopes. Although it only contains 15 stars, NGC-1502 is a striking object through a small aperture. It shines at 5.3 magnitude and occupies 7 minutes of arc. Three and four-inch scopes show it to be tightly packed with many stars of differing magnitudes. On nights with good seeing you can find it with binoculars. Webb called this cluster "an elegant group with a seventh magnitude pair, preceded by a wider one." Although it has few members, this cluster's tight packaging makes it a plus for winter evenings.

If you have a few extra moments on such a clear night, try finding the beautiful large spiral **IC-342**. Although an 8-inch or larger scope is preferable, this galaxy can be seen in smaller instruments. Thought to be a member of the Local Group, it was discovered in 1890 by W.F. Denning. In an 8-inch, IC-342 appears as a 9th magnitude face-on spiral with a bright nucleus surrounded by a faint, hazy glow. It is similar in shape to M-101 in Ursa Major, but is much closer to the Milky Way. This galaxy is of great interest to astronomers since it could be the fourth spiral member of our Local Group — all the rest are dwarf ellipticals. Long-exposure observatory photographs reveal its beautiful spiral structure, plus many large emission nebulae and stellar clusters in the spiral arms.

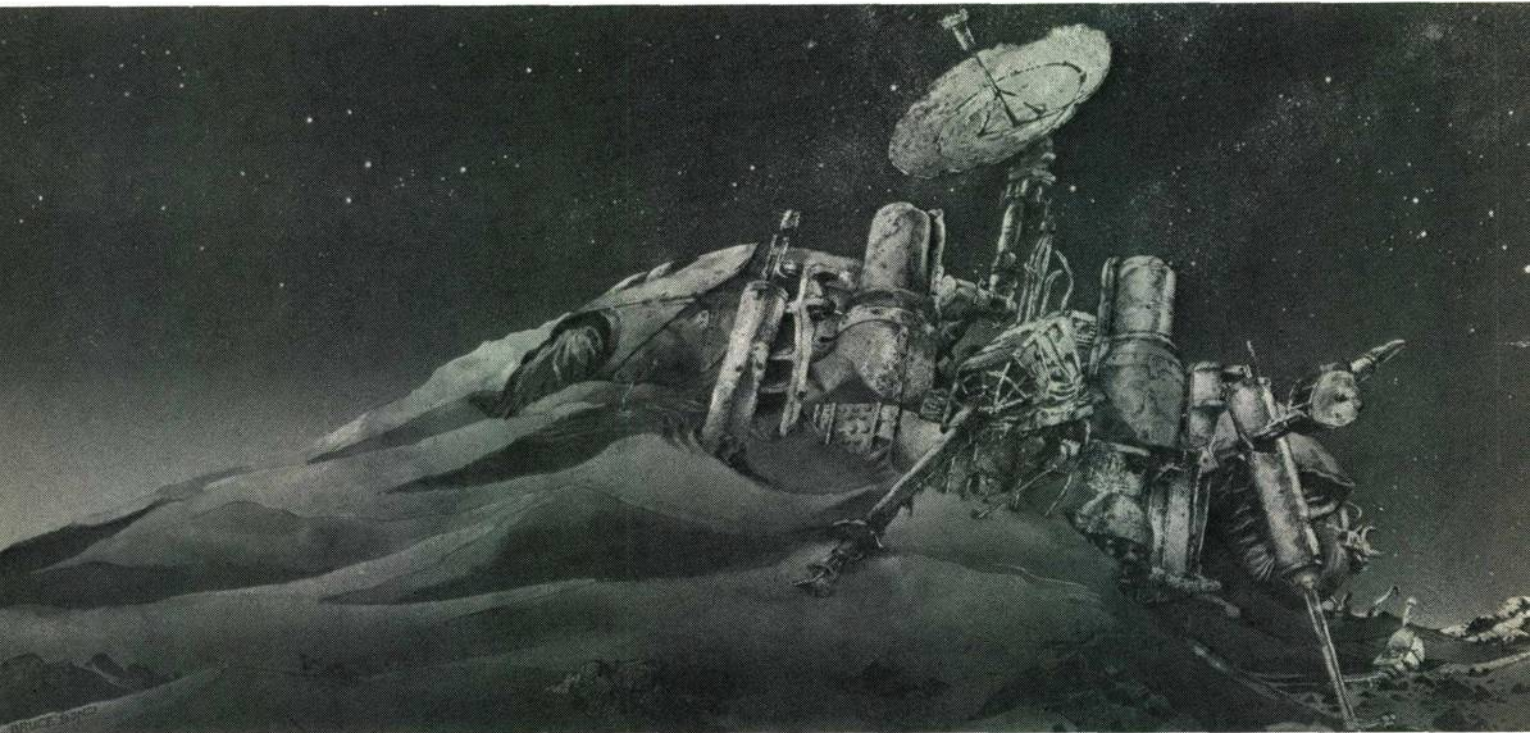
By this time, your toes might be getting numb, but you've also seen many fine sights that you overlooked before. Those dim, seemingly uninteresting constellations — like Camelopardalis — are actually full of the deep-sky objects you love to track down and observe. And even though there are no bright stars to guide you, they are still easy to find if the night is clear and you don't mind spending a little time out in the cold — before you curl up in front of the fireplace.



Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (1981)	Dec.
U	m★	7.7-9.5	412d	03h37m	+62°29'	03h40m	+62°35'
IC 342	\$S	9.1	27'x24'	03h42m	+67°54'	03h45m	+68°00'
NGC-1501	■	10.0	56"x48"	04h05m	+60°51'	04h07m	+60°56'
NGC-1502	○	5.3	7.0'	04h05m	+62°15'	04h08m	+62°20'
ST	n★	7.0-8.4	irr.	04h46m	+68°05'	04h49m	+68°08'
Alpha (α)	★	4.4	—	04h49m	+66°16'	04h52m	+66°19'
Beta (β)	★	4.2	—	04h59m	+60°22'	05h02m	+60°25'
NGC-2403	\$S	8.8	29'x15'	07h34m	+65°40'	07h37m	+65°36'
Z	n★	9.9-14.3	irr.	08h20m	+73°16'	08h23m	+73°10'
32	★ ²	5.3, 5.8	22'	12h49m	+83°41'	12h49m	+83°31'

- ★ Star
- ★² Double Star
- ★³ Triple Star
- m★ Regular Variable
- n★ Irregular Variable
- h★ Eclipsing Variable
- Open Cluster
- Globular Cluster
- Planetary Nebula
- Bright Diffuse Nebula
- \$0 Elliptical Galaxy
- \$S Spiral Galaxy
- \$J Barred Spiral Galaxy
- \$# Peculiar/Irregular Galaxy

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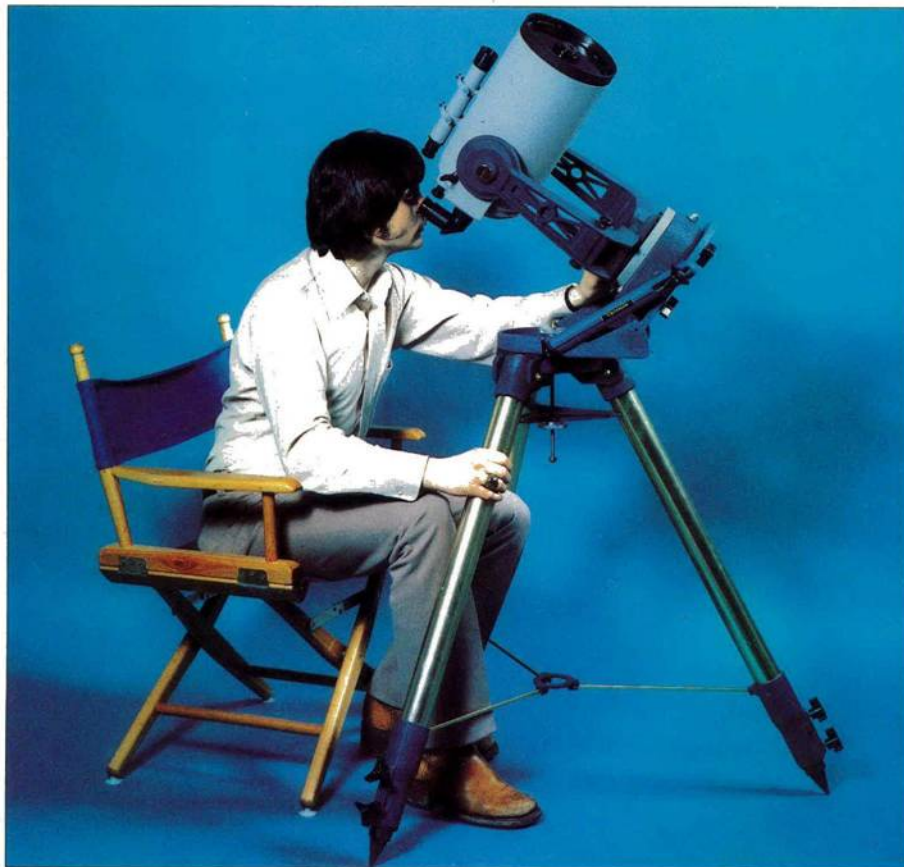
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